Sedimentological studies of Ganga River sediments between Rishikesh and Kachhla, Uttar Pradesh

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This is to certify that the work presented in this thesis has been carried out by **Mr. Adal Singh** M.Sc.,M.Phil (Alig.), Senior Research Fellow of C.S.I.R. under my supervision. The work presented herein is an original contribution and has not been published anywhere in part or in full. It has not been submitted for any other degree at this or any other university.

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INTRODUCTION

The study of the modern sediments has attracted the attention of the geologists in recent years in order to study the mechanism of fluvial sedimentation. The study of modern sediments provides an opportunity to understand the processes and products in different known environments which can be useful in the interpretation of the ancient sediments. The processes operating leave their imprints in the geological record. Braided and meandering are the two main types of rivers. However, the meandering rivers are widely understood. The existing geological literature shows little agreement about what constitute a braided river and how a typical braided river deposit looks like. It is a common observation that the channels in braided rivers and their intervening bars are very short lived due to lateral migration and scours and fill of the channels. Therefore, the preservation of bar deposits is a chance.

Few modern braided sandy rivers have been described sedimentologically. The classic studies made include the Brahmaputra (Coleman, 1969), Platte (Smith, 1970), Tana (Collinson, 1970), and South Saskatchewan (Cant and Walker, 1978).

Ganga River:

The river Ganga is not known by this name either in the beginning or at its end. Ganga rises in the Garhwal Himalaya (30° 35'N, 79° 7'E) under the name of Bhagirathi. The river Bhagirathi which originates from the icecave of Gaumukh at a height of 4100 m, in Garhwal Himalaya is accepted traditionally as the original Ganga. The river cuts its path through the Himalaya till another head stream Alaknanda, which also carries the water of its tributary Mandakini, meets the river Bhagirathi at Devprayag. Thus, the three - Bhagirathi, Alaknanda and Mandakini join to form the Ganga River system. The Ganga River basin covers a wide variety of land forms, from featureless plains in the central belt to mighty Himalayan ranges in the north with deep valleys and glaciers and plateaus and hills in the south with mountain climate at upper reaches and humid subtropical climate with dry winter in the lower reaches (Subramanian and Sitasawat, 1987).

Ganga plain is a part of the active foreland basin developed on the underthrusting Indian Plate, in response to the thrust-fold belt loading in the Himalaya (Singh, 1988). The rivers of northern part of the Ganga plain flow southwards following regional south sloping surface formed by expanding-contracting alluvial fans. Present day active alluvial fans make only 20-30 km wide belt. In the central part of the Ganga plain, river swings in east and south east directions and seems to flow on easterly sloping regional surface.The river carries high sediment load. The active river channel has been aggrading vertically and depositing a lot of sediment within the channel during recent past. Ganga plain is aggradational, where active net deposition is taking place. In the northern part of the basin, the sediments are mostly gravels, and medium to coarse sand alternating with muddy sediments.

After traversing nearly 280 km. the river descends into the plains at Rishikesh. The river Ganga along with its tributaries have made an elongated basin of fluvial sediments (Ganga plain) running E-W- in front of rising Himalaya and covers an area of about 850000 km^2 (Kumar and Singh, 1978). Rapid sedimentation is taking place in the Ganga plain and E-W running weak zones control the course of main river and the pattern of sedimentation (Singh and Rastogi, 1973). The thickness of alluvium is 500-1000 m near foot hills and descending southwards , where it may be few tens of meters thick (Kumar and Singh, 1978). Ganga River in Uttar Pradesh shows prominent terraces on the southern side, and an extensive flood plain on the northern side, where ox-bow lakes, ponds, and swamps are developed. The velocity of the river suddenly decreases as it enters the sea and drops its entire load, finally forming a delta. The Ganga (and Brahmaputra) delta forms prolonged north-south bars projecting into the sea and referred to as 'birdfoot type delta' (Rao, 1975).

The river during its journey to the sea carries large amount of detritus throughout its path in the hilly track for nearly 250 km. and passes through parts of western and central Himalayas (Mehrotra, 1986). As the river descends in the plains near Rishikesh, it passes through a thick sedimentary sequence of Siwalik hills. The nature and amount of sediment available for transport depends upon the rate of erosion, which in turn is dependent on weathering processes, fluctuation in temperature, and periodicity of rains etc.

The discharge of the river Ganga is seasonally controlled. The river maintains low discharge in winter season, and the discharge increases in late spring. In rainy season discharge reaches its peak in the month of July and August and decreases in October and November.

Throughout the course of study, generally the river shows three topographical levels (Fig. 1). These levels are distinguished on the basis of elevation, amount of vegetation cover and fluvial activity. Level I is the lowest level and is marked by active channels. It shows no vegetation and is very active part of the river. Level II is higher than level I. Only few channels are active on this level and is subjected to widespread fluvial activity during flood stage. Level III is highest having the vegetative cover. All channels of level III are abandoned and dry except in rainy season.

Fig. 1

Fig. 1. Gravelly bars showing various topographical levels.

Location:

The area under study lies in between Rishikesh and Kachhla, 78°15' to 79°15' longitude and 27°55' to 30°8' latitude and covers an area about 350 km. in length (Fig.2).

Purpose of Present Study:

Recent studies of modern sediments have no doubt enhanced our understanding of sedimentation model. In India, modern river systems have been investigated mostly by Civil Engineers from the point of view of channel patterns, hydraulic behaviour and rate of erosion. However, little attention has been paid so far by sedimentologists to the Indian rivers. In India, sedimentological studies of modern sediments have been made by Coleman (1969), Singh (1977), Kumar and Singh (1978), Parkash et al., (1983), Wells and Dorr, Jr. (1987), and Bristov (1987). Sedimentological information is vitally lacking for the proper evaluation of sedimentation model of modern Indian river systems. The sedimentological study of Ganga sediments have practically been untouched. Therefore, an attempt has been made to study the processes and products of the river Ganga. A systematic study of Ganga River sediments between Rishikesh and Kachhla, U.P. (Fig. 1) provides excellent opportunity to study the modern river sediments in known environment.

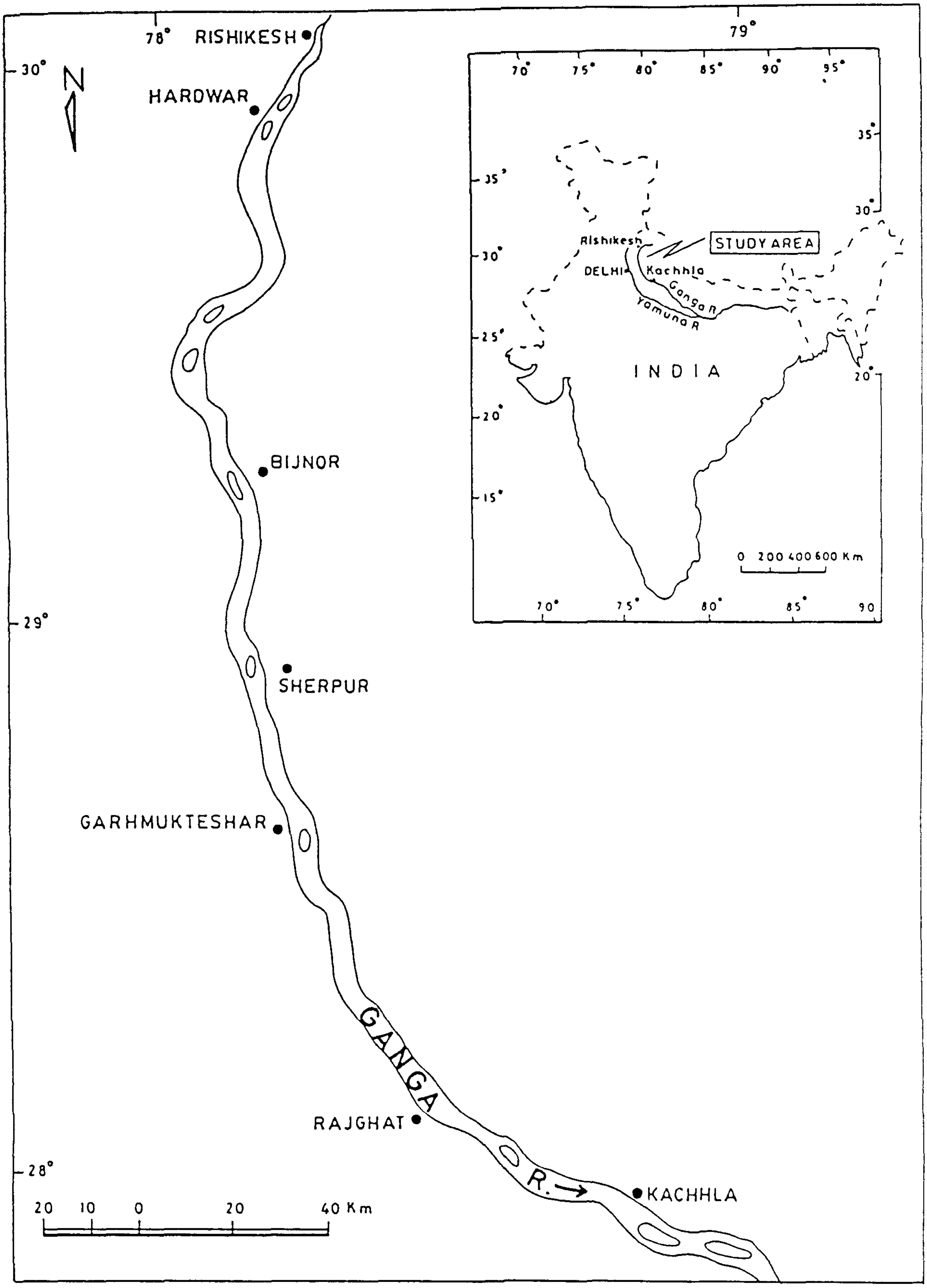


FIG.2 MAP OF THE STUDY AREA

In the present study, the emphasis has been laid on appropriate quantitative methods as and where possible for collecting relevant data for interpretation of alluvial fan and braided river deposits. The sedimentological study makes it possible for developing a suitable model for fluvial dynamics.

Scope of Present Study:

During the preliminary investigations seven stations were selected for detailed study namely Rishikesh, Hardwar, Bijnor, Sherpur, Garhmukteshar, Rajghat and Kachhla. Trenches were dug at these stations and sections were measured. The lithological characters, sedimentary facies were carefully recorded in known environment to develop a sedimentological model. The size analysis was done with the help of standard A.S.T.M. sieves. For the study of mineral composition, 32 mounted grain slides of sand and 15 mounted grain slides of heavy minerals were examined. With the help of dip azimuths of planar and trough cross-stratifications a flow pattern map was made. The measurements of the cross-stratification received the maximum attention as this structure occurs most commonly.

On the basis of above study, two separate sedimentation models one for alluvial fan and other for braided river deposits have been developed.

CHAPTER I

ALLUVIAL FAN DEPOSITS

GENERAL REMARKS:

The alluvial fan deposits are the distinctive terrestrial stratigraphic units. The surface of a fan deposits forms a segment of a cone that radiates downslope from the point where the stream leaves the mountains (Fig. 3a). Alluvial fans are conical and lobate or arcuate accumulations of predominantly coarse clastics extending from a mountain front or escarpment across an adjacent lowland where the sediment charged water undergoes a sudden reduction in slope and flow velocity (Klein, 1982, P.5; Galloway and Hobday, 1983 P. 25; Fraser and Suttner, 1986). Denny (1967) described that settling of highland and lowland side by side is the prime requisite of fan formation.

Alluvial fans are indicators of sharp terrestrial relief and climatic extremes (Rust and Koster, 1984; Wilson, 1973). In humid regions, as in alps or the Himalayas, alluvial fan deposits laid down by streams are of considerable magnitude (Blissenbach, 1954).

The fans have great economic importance. Many of the groundwater reservoirs are the result of alluvial fan deposits. Alluvial fans recharge the groundwater reservoirs that fringe the basin. The surfaces of many fans are highly suitable for agriculture, urban, and industrial uses. Much of the world's gold and uranium production is from placers in ancient fan deposits of the Witwatersrand , South Africa (Minter, 1978; Smith and Minter, 1980). The geometry, high groundwater transmissivity, and geochemical and permeability gradients of wet alluvial fan systems make them one of the most favourable hosts or epigenetic uranium deposits. The marine reworked fringes of fan deltas are excellent oil and gas reservoirs.

Thick, laterally impersistant gravelly deposits were studied around Rishikesh. Here, the river Ganga confined by narrow valleys emerges on to a plain characterised by a radial sediment dispersal pattern (Fig. 3c). The alluvial fan development occurs in response to a sharp drop in transport efficiency. The gravelly zone where the river emerges on to a plain from the mountains is called Bhaber zone which extends all along the Himalayan front. The width of the Bhaber zone on fan is 8 to 24 km. and 9.5 - 17 m/km. in slope (Wells and Dorr, JR, 1987, p. 51). The Bhaber is a zone of braided rivers and infiltration of surface water. The northern boundary of the Bhaber belt is marked by the Siwalik hill ranges and the southern limit is characterised by a line of issuing water (spring line). This belt is composed of piedmont deposits formed due to lateral coalescence of fan deposits of innumberable streams emerging out of hills. Lithologically, Bhaber belt is constituted mainly by unsorted mixture of sands,

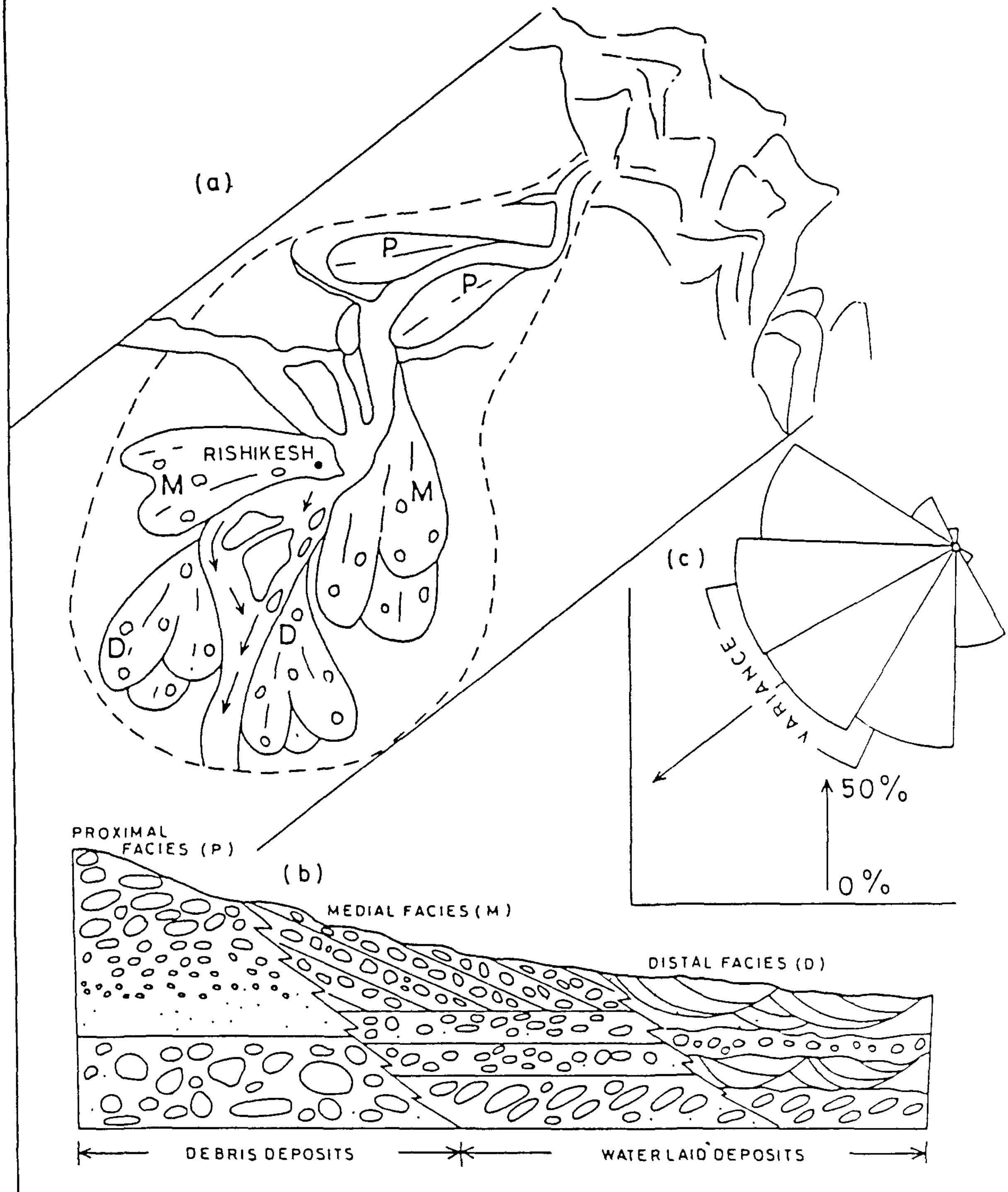


FIG. 3 DEPOSITIONAL MODEL OF ALLUVIAL FAN
(a) SHOWING MORPHOLOGICAL PROFILE
(b) DISTRIBUTION OF FAN FACIES
(c) RADIATING SEDIMENT DISPERSAL PATTERN

pebbles, cobbles, and boulders with some silt.

Methods of Study:

For the study of fan deposits, trenches were dug with the help of showel to expose the three dimensional geometry of the deposits. The depth of trenches ranges from 2 to 3 m, and length from 3 to 5 m. The geometry, sedimentary facies, orientation and arrangement of clasts were recorded carefully. These observed characteristics made possible to identify the alluvial fans and processes responsible for their development.

Alluvial Fan Facies:

The fan sediments show progressive change in internal sedimentary structure and lithology in the down fan direction (Fig. 3b). Downstream, the alluvial fan facies show increase in number of cross-stratal sets and decrease in size of clasts. The distal part of the alluvial fan is denoted by marked slope change, coupled with a loss of radial sediment dispersal pattern with the increase in fine clasts. Large scale trough cross-stratified gravelly sand and channelised gravelly deposits developed in the distal alluvial fan facies show the transitional relationship with the down stream braided river deposits (Fig. 4).

On the basis of field characters the different facies namely-proximal, medial and distal (Fig. 3b) have been recognised.

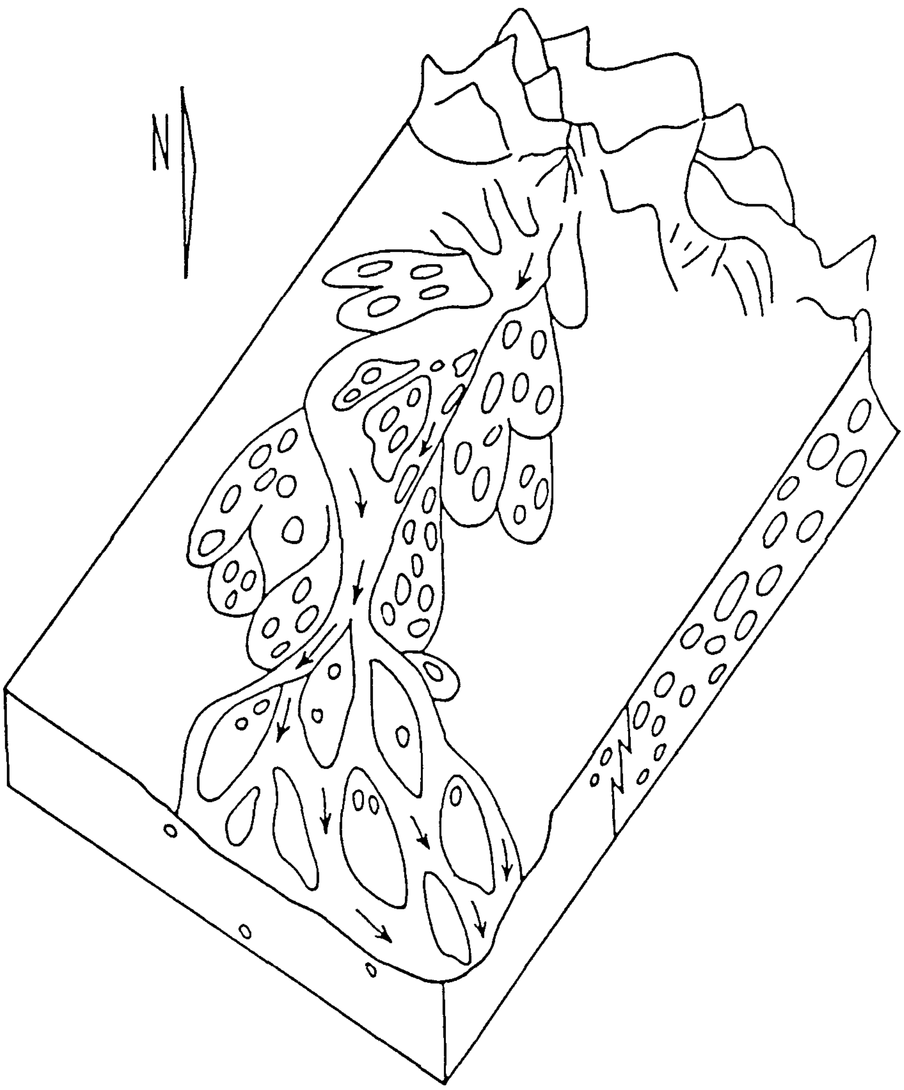


FIG. 4 SHOWING TRANSITIONAL RELATIONSHIP OF ALUVIAL FAN DEPOSITS WITH BRAIDED RIVER DEPOSITS

Proximal facies: The deposits of this facies are marked by high slope angles and comprises the apical zone of the fan complex. The main sediment processes in this zone are predominantly debris flows with subordinate sieve deposits. As a result, the boulders and gravels are matrix supported, poorly sorted, having lack of fabric and stratification. However, the coarsening upward sequence is also observed.

Medial facies: The medial facies which occurs in central part of alluvial fan deposits is characterised by water-laid deposits with slightly subordinate debris flow deposits. The reworking of debris flows results in improved sorting of the sediments. The sedimentary structures are gravelly horizontal stratification and planar cross-stratification with increasing sand content. Imbricated gravel clasts are also observed.

Distal facies: This facies occurs in the toe of an alluvial fan (Fig. 3b), and is characterised by low slope angles with water-laid deposits. The sorting is improved in comparison to proximal and medial facies. The primary sedimentary structures developed are large scale sandy trough cross-stratification and gravelly channel deposits. The dominant lithology is sand. Cross-stratification, and imbricated gravel clasts are common.

DEPOSITIONAL PROCESSES OF FAN:

Several depositional processes of alluvial fans have been described (Hook, 1967, 1968; Denny, 1967; Bull, 1972; Spearing, 1975). Fans in humid tropical climates are less common, as the climate induces chemical weathering rather than mechanical production of coarse detritus, and dense vegetation protects slopes. But short term fluctuations produce debris flows in humid areas as described by Curry (1966); Broscoe and Thompson (1969); Winder (1965). Fans, whose surface processes are dominated by streams flowing in channels have also been termed 'humid fans' (Collinson, 1986, p. 30; Pettijohn et al, 1987, p.362). The largest described fan is that of Kosi River which emerges from the Himalayan foothills to build a fan in the Ganga valley, is a product of stream processes alone (Schramm, 1981; Collinson, 1986, p.30).

The major processes of sedimentation revealed from alluvial fans in the study area include debris deposits and water-laid deposits (Fig. 3b). It has been suggested that fans in humid climate settings produce relatively fewer debris flows, and are therefore dominated by water-laid deposits (Schumm, 1977; Galloway and Hobday, 1983). However, in humid regions fans contain abundant debris flow deposits (Broscoe and Thompson, 1969). The fan deposits are active seasonally in response to monsoonal floods or ice melting in the catchment area.

Debris Flow Deposits: Debris flow deposits have been described by various workers (Schumm, 1977; Curry, 1966; Broscoe and Thompson, 1969; Winder, 1965; Gloppen and Steel, 1981). The initiation of debris flows requires accumulation of fine debris, and steep slopes to promote rapid runoff and erosion (Schumm, 1973; Heward, 1978; Collinson, 1986). Hampton (1975); Morison and Hein (1987, p. 208) described gravity deposits as debris flow deposits. Bull (1977) described that debris flows are promoted by steep slopes, lack of vegetation, short period of abundant water supply and a source providing debris with a muddy matrix.

Debris flows are poorly sorted, matrix supported, characteristically deposited in the proximal part. The deposits lack internal stratification and the clasts have no organised fabric (Fig. 5). All these characters are indicative of debris flows, deposited in the proximal part of the fan (Datta, 1988; McArthur, 1987). Coarsening upward sequence (Fig. 5) also represents the debris flow deposits. 2-3 m thick sections of debris flow deposits were observed.

Interpretation: Factors that promote debris flows are abundant water (usually intense rainfall) over short periods of time at irregular intervals, steep slopes having insufficient vegetation cover to promote rapid erosion and a source material that provide a matrix of fine sediments. All clast sizes are dumped together as the flow freezes, giving a very poorly sorted deposit with larger clasts embedded in the fine matrix. Clasts without orientation imply transport and depositional processes in which the clasts are less free to move relative to each other.

The massive unit (Gms, terminology after Miall, 1978) was deposited by sediment gravity flows initiated by high seasonal flood runoff over entire surface of the bar (Fig.5 & 7a).

Coarsening upward sequence (Fig. 6 & 7b) is interpreted in terms of energy variations related technique, relief, and climate (Collinson and Thompson, 1982, p. 118). Coarsening upward sequence is the result of interfingering of channel bars comprising coarse gravels/boulders with gravel or pebbly sand foresets.

Coarsening upward sequence was developed due to switching of one fan lobe to another during progradation of fan under high energy conditions (Koster, 1984; Watt, 1988; Datta, 1988). During the progradation the gravelly/bouldery channel bars interfinger with fine gravelly or pebbly sand bars. Coarsening upward sequence is the feature of debris flow deposits resulted due to subaquous mass movement (Brodzikowski and Vanloon, 1987; Kingsley, 1987, p. 367).

Fig. 5

Fig. 6

Fig. 5. Debris deposits consisting gravels and boulders with sandy matrix. Gravels and boulders are randomly oriented.

Fig. 6. Debris deposits showing coarsening upward sequence. The size of the sediments increases from coarse sand at the base to gravels and boulders at the top.

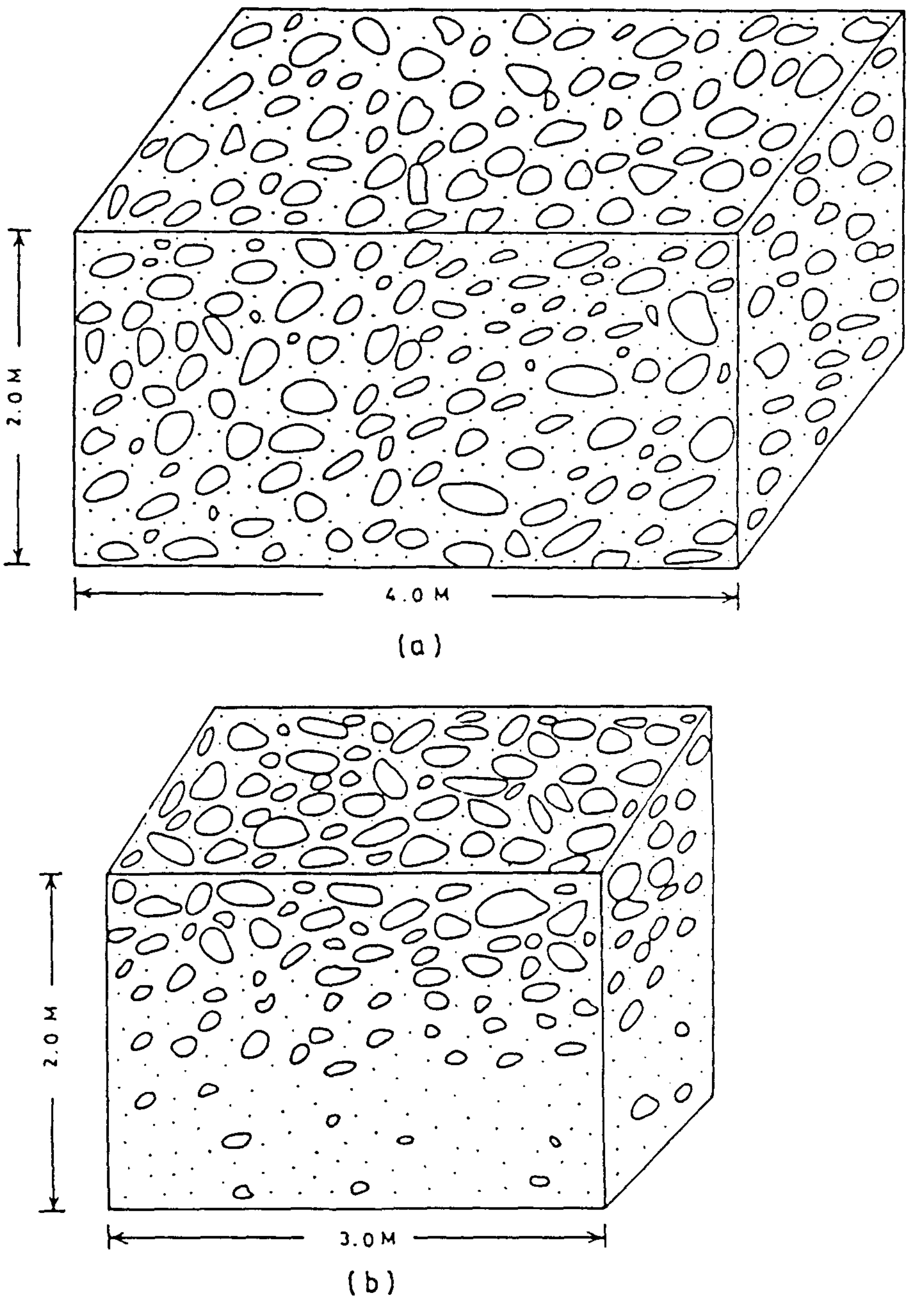


FIG. 7 (a) SIEVE DEPOSITS SHOWING MASSIVE UNIT
(b) DEBRIS DEPOSITS SHOWING COARSENING UPWARD SEQUENCE

Water-laid Deposits: Three types of water-laid deposits recognised in the study area are sheet flood, sieve and stream channel deposits. The stream channel deposits have been reported from various environments but sheet flood and sieve deposits are most likely to be preserved if deposited on an alluvial fan. The nature of water-laid deposits in the study shows progressive change in downstream. There is an increase in the abundance of cross- stratal sets (both planar and trough) with transitions from coarse gravel through clast supported fine gravel, and sand matrix supported gravel to sand. The water-laid deposits are marked by better stratification, better developed clast imbrication and roundness of clasts is also better than the debris flow deposits.

Sheet Flood Deposits

During high discharge, water overflows the channels and sediment spread out producing a sheet like deposit. Sheets of sediments were deposited by surges of sediment laden water which spread out from the channels on the fan. Sheets of water-laid sediments which are not associated with channels are the sheet flood deposits (Wasson, 1977). The sheets were deposited by widening of flow, decrease in depth rather than change in gradient. The shallow distributary channels were rapidly filled and than shifted to a short distance resulting into a sheet like deposit. During peak discharge, sediment laden sheet floods spread over the entire surface.

A well developed orientation of clasts strongly suggests that individual clasts have moved freely with respect to each other, and have assumed an orientation imposed by flow mechanism. Figures 8, 9, 10a & b show imbricate arrangement of clasts, parallel to current direction. Such fabric does not appear to develop by rolling, it is a reliable indicator of transport processes that maintain pebbles and cobbles in disperson above the bed. Figures 11 & 12 show sheet flood deposits having planar cross-stratification in cosets, and horizontal stratification. The thickness of planar cross-statification ranges from 65 to 85 cm and thickness of each forest ranges from 5 to 8 cm and consists gravel with sand. The thickness of horizontal stratification is nearly 27 cm consisting gravel with sand. The massive units are upto 3 m thick having boulders and gravels with sand.

Sieve Deposits

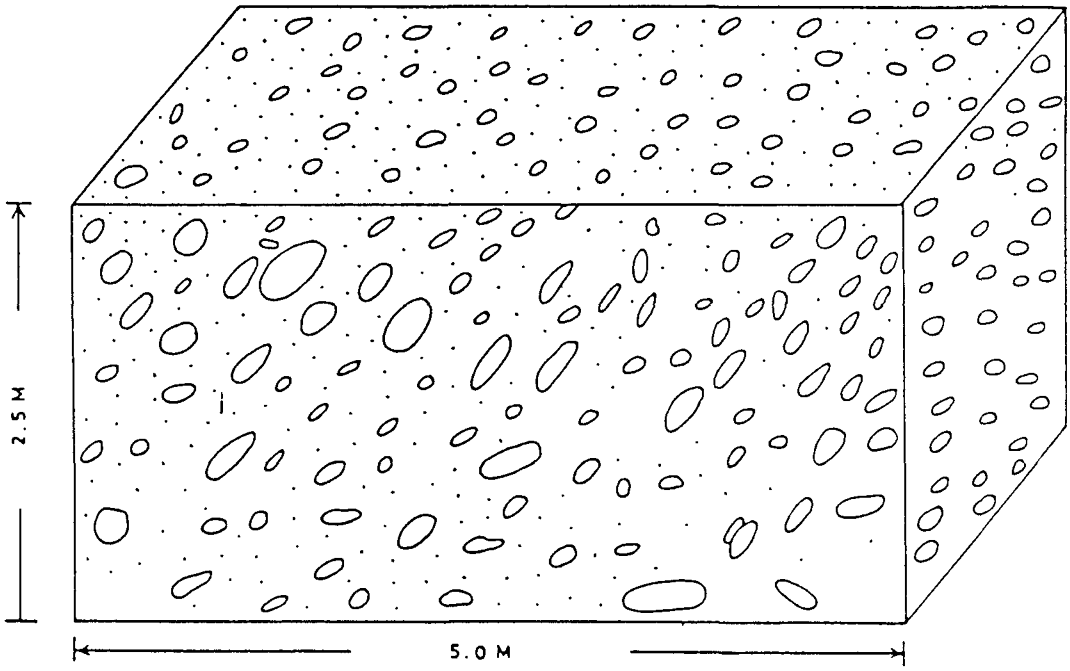
The fan deposits are so much transmissive that sometime river loses all its water and apparently disappears to emerge down stream where the transmissive zone cut the land surface. Moreover, fan deposits due to its high permeability forms the recharge area for all the deeper aquifers (water bearing strata) of the Ganga basin. Under such conditions lobes of gravels from 1 to 2 m in thickness were deposited. Sufficient

Fig. 8

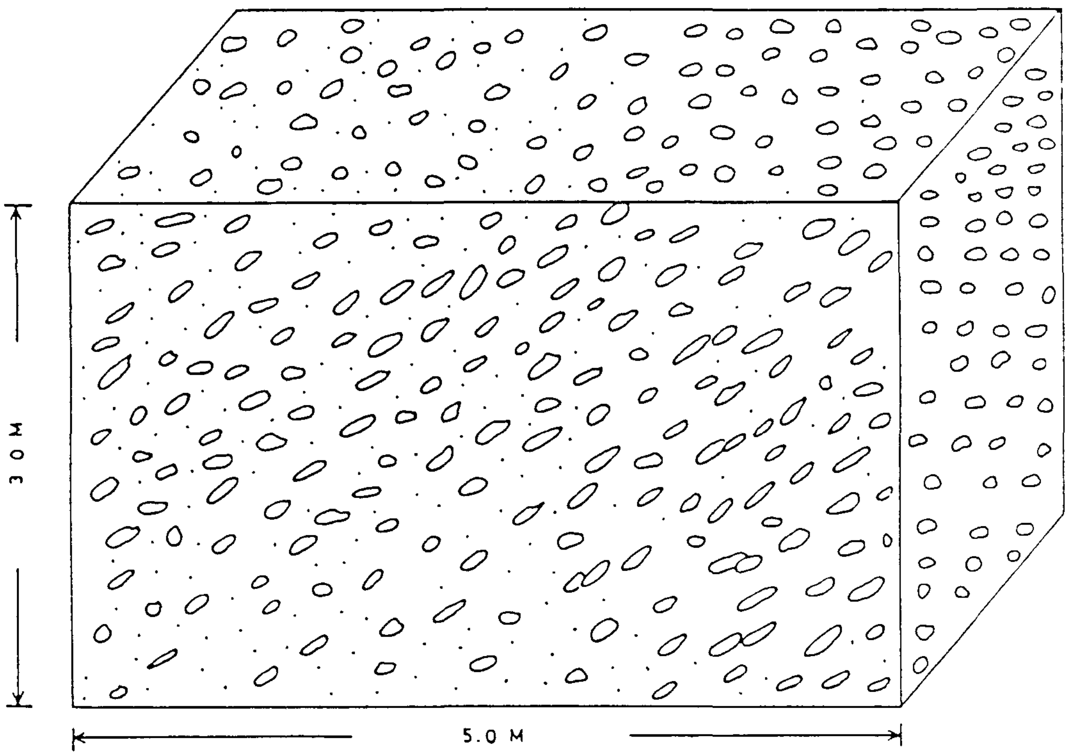
Fig. 9

Fig. 8. Water-laid deposits showing imbrication of gravel clasts.

Fig. 9. Water-laid deposits showing imbricate arrangement of gravels and boulders.



(a)



(b)

FIG. 10 (a & b) SHOWING IMBRICATION

Fig. 11

Fig. 12

Fig. 11. Sheet flood deposits showing cosets of cross-stratification in sandy gravel. In the middle part massive unit consisting sandy gravel is terminated by planar cross-stratification.

Fig. 12. Sheet flood deposit showing planar cross-stratification in sandy gravel in the upper part and horizontal stratification in the lower part.

transmissable substrata were produced when the source area supplied little amount of sand and silt to the fan. Such lobate gravelly deposits are described as 'Sieve deposits' (Hook, 1967; Gloppen and Steel, 1981; Collinson, 1986). The deposited lobes are poorly sorted containing boulders and gravels with sand (Fig. 13 & 14). The clasts are subangular to rounded showing random disperson.

Stream Channel Deposits

The streams emerging on to a fan, bifurcate and assume radiating pattern. The stream flow processes are influenced by fluctuating conditions. During peak discharge, sediment laden floods spread across the entire surface and channels were entrenched into a fan in which gravels and boulders were deposited as channel lag deposits (Fig. 15c). The channel deposits are lacking bedding characters. The interspaces between gravels and boulders were filled with sand. The lower and upper bounding surfaces of channel deposits are erosional. Trough cross-stratification in stream channel deposits is defined by concave up stratification. The thickness of trough cross-stratification ranges in between 60-80 cm

Interpretation: The water-laid deposits marked with imbricate arrangement (Gm) of clasts (Fig. 8, 9, 10a & b) in which long axes of clasts are inclined in upstream direction, indicate

Fig. 13

Fig. 14

Fig. 13. Sandy gravels deposited in the form of lobes, [illegible]
ing sieve deposits.

Fig. 14. Sandy gravels deposited in the form of lob[illegible]
ing sieve deposits.

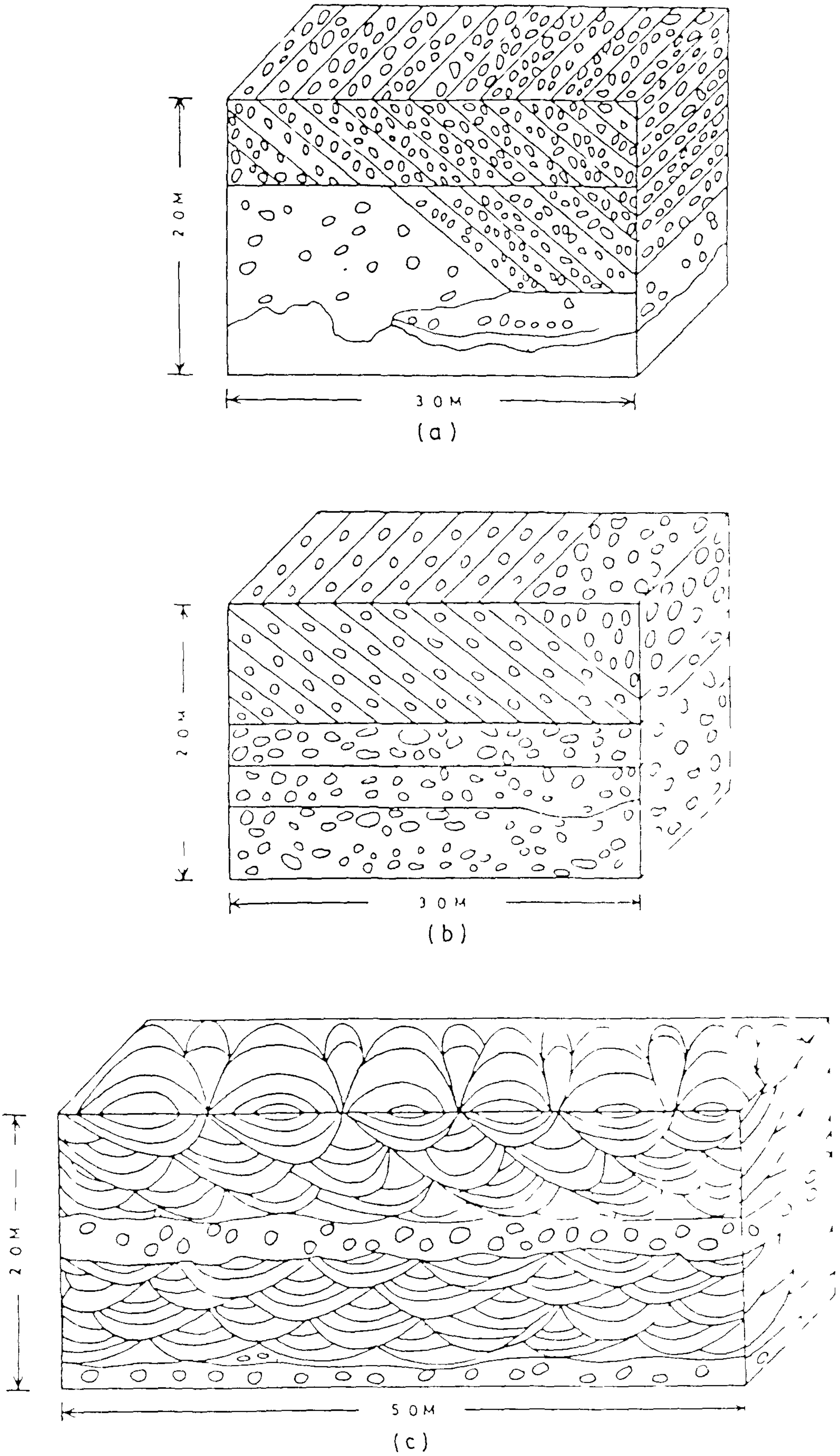


FIG 15 (a) SHOWING MASSIVE UNIT AND PLANAR CROSS-STRATIFICATION
(b) SHOWING HORIZONTAL STRATIFICATION AND PLANAR CROSS-STRATIFICATION
(c) SHOWING STREAM CHANNEL LAG DEPOSITS AND
LARGE SCALE TROUGH CROSS-STRATIFICATION

reworking and free movement of clasts with respect to each other (Morison and Hein, 1987, p. 209). Orientation of long axes parallel to flow is interpreted as evidence of rapid transport capable of maintaining large clasts in the dispersion above the bed (Lindholm, 1987, p. 61).

In the lower part (Fig. 11 & 15a) the massive unit terminated by planar cross-stratification (Gp) clearly indicates that sediments were migrated on the bar surface and slip down and deposited on the avalanche face resulting planar cross-stratification. Planar cross-stratification is the characteristic feature of sheet flood deposits (Brodzikowski and Vanloon, 1987). Avalanche slip faces lead to the development of sets of cross-stratified gravel reflecting bar growth (Collinson, 1986, p. 23; Galloway and Hobday, 1983). However the individual foresets in the cross-stratified units were deposited under wholly fluvial conditions. Planar cross-stratification is the result of down stream progradation of high relief bed forms (Morison and Hein, 1987, p.211).

In the gravelly braided stream environment, large amount of crudely horizontal or very low angle strata form mainly as longitudinal, diagonal, or medial bars (Hein and Walker, 1977; Rust, 1978). The horizontal stratification (Gh; Fig.15c) was deposited on the surface of longitudinal bar (Galloway and Hobday, 1983). The clasts are matrix supported. Both clasts and matrix were deposited more or less simultaneously, wher rapid deposition was going on. On the surface of longitudina bar, flat subhorizontal stratification in gravels was developed during high discharge and relatively shallow current depth (Collinson and Thompson, 1982, p. 110).

Stream channel deposits (Gs) are the result of high velocity currents which were able to entrench the fan surface, consequently the gravels and boulders were deposited on the channelised surface (Fig. 15c) as channel lag deposits (Collinson, 1986). The interspaces were filled with sand during low velocity currents. The erosional base suggests that gravel was deposited by channelised sediment laden gravelly flow .

The gravelly channel lag deposits are followed by large scale trough cross-stratification (St). The large scale trough cross-stratification underlain by gravelly channel lag deposit clearly reveals its development under low velocity conditions due to migration of dunes with sinuous crest line (Collinson, 1986). After gravelly channel lag deposits the velocity decreased and current was able to transport only sandy material during which large scale trough cross-stratification was developed. The presence of large quantity of mica is also the evidence of low energy conditions during the development of large scale trough cross-stratification.

CHAPTER II

FACIES DESCRIPTION

GENERAL REMARKS:

The term 'facies' was introduced into geology by Nicholaus Steno (1699). It meant the entire aspect of part of the earth's surface during a certain interval of geological time. The modern usage was introduced by Gress (1838), who used the term to imply the sum total of the lithological and palaeontological aspects of a stratigraph unit.

Facies studies have been extended rapidly during the past two decades with the realization of Walther's (189? classical concept. The occurrence of a facies and its position in a sedimentary sequence has genetic significance. Recent workers have given a new direction to this concept, and set out to analyse sedimentary facies of fluvial environments in vertical sequences quantitatively and objectively (Allen, 1970; Miall, 1973, 1977, 1978; Cant and Walker, 1976; Rust, 1978). Moore (1949) revised the original concept and suggested that the term facies should be considere to 'comprise any areally segregated part of a designated rock division in which physical and/or organic characters differ significantly from those of another part or parts'.

The more common (modern) usage is examplified by de Raff et al., (1965) who subdivided a group of the formations into a cyclic repetition of a number of facies distinguished by 'lithological, structural and organic aspects detactable in the field'. According to him the key to the interpretation of facies is to combine observations made on their spatial relations and internal characteristics (lithology and sedimentary structures) with comparative information from other well studied stratigraphic units, and particularly from studies of modern sedimentary environments. Today sedimentologists most commonly use the word facies (descriptive sedimentary facies) to mean a certain volume of rock that can be characterised by a set of features, such as grain size, geometry and structure, that distinguish it from other rock units and interpretative sedimentary facies as a level summarising the interpretation of the processes and environments of deposition of a certain rock unit (Anderton, 1985, p. 31). According to Reading (1986 'A facies is a body of rock with specified characteristics'. In sedimentary sequence it is designated by colour, stratification, composition, texture, fossil and sedimentary structures.

Miall (1984, p 133) described the word facies in both descriptive and an interpretive sense. Descriptive facies such as lithofacies refer to certain observable attributes of sedimentary rock bodies, which can be interpreted in terms of depositional process. The term facies can also be used in an interpretive sense, for groups of rocks that are thought to have been formed under similar conditions.

The term 'facies' is broadly used when one has to consider modern environments as well as ancient rocks. In the case of modern environment, of course, such a facies level is descriptive not interpretative. In recent sediments an element of interpretation will usually creep in if the term facies is used to include a depositional process which has not been directly observed.

Thus, the present status, and concept of sedimentary facies have considerably enhanced our understanding of sedimentary environments and sedimentary processes in the braided river deposits. The facies have been described on the basis of lithology, grain size, primary sedimentary structure and geometry. These facies were named and coded individually following a modified coded scheme of Miall (1978). The facies code consists of two parts, a capital letter of dominant lithology, and a, small letter of sedimentary structure of each facies. The following facies were recognised.

1. Gravelly channel facies (Gs);
2. Sandy channel facies (Ss);
3. Trough cross-stratified sandy facies (St);
4. Planar cross-stratified sandy facies (Sp);

5. Ripple drift cross laminated sandy facies (Sr);
6. Convolute laminated fine sand, silt and clay facies (Fc)
7. Parallel laminated fine sand, silt and clay facies (Fl);
8. Massive sandy facies (Sm), and massive silt and clay facies (Fm);
9. Horizontal stratified sandy facies (Sh);
10. Lenticular sany facies (Sl).

Gravelly Channel Facies (Gs):

Gravelly channel facies have been observed at Hardwar. Laterally and vertically this facies is embedded into medium and fine sand (Fig. 16). The clasts are of pebble and cobble size, generally subrounded to well rounded ranging 2 cm to 10 cm in diameter. The lense shaped gravelly channel facies, pinches out laterally within few meters, having on an average 4 m width with maximum thickness of 40 cm and tens of meters in length. The base of this facies is erosional and is devoid of any visible internal structure. The gravelly channel deposits are mostly clast supported but are locally sandy matrix supported.

Interpretation:

The clast supported massive gravelly channel facie embedded vertically and laterally in medium to fine sand is interpreted as channel lag or longitudinal braid ba

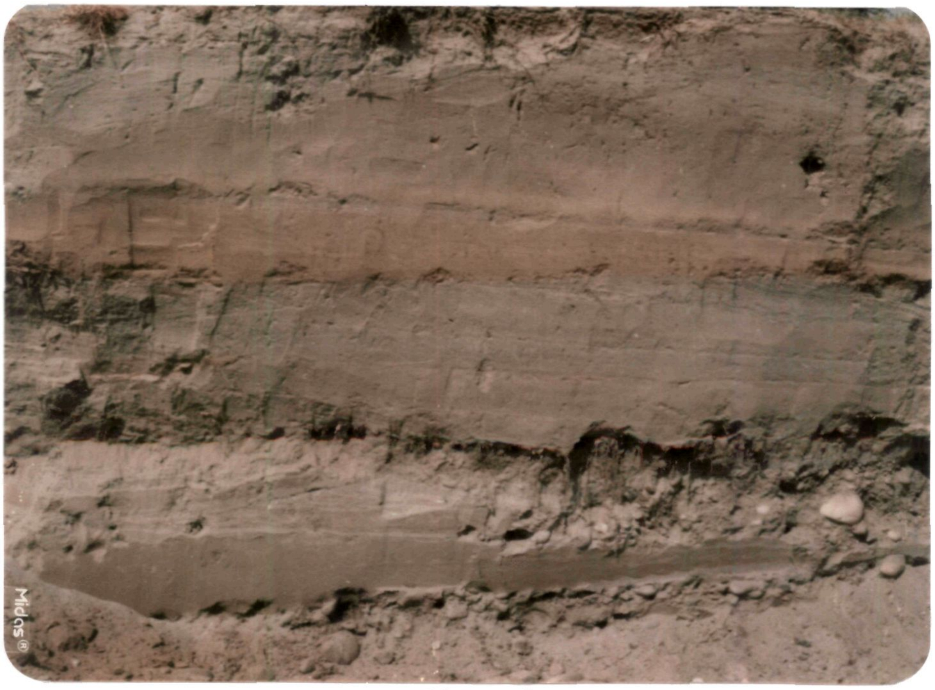


Fig. 16

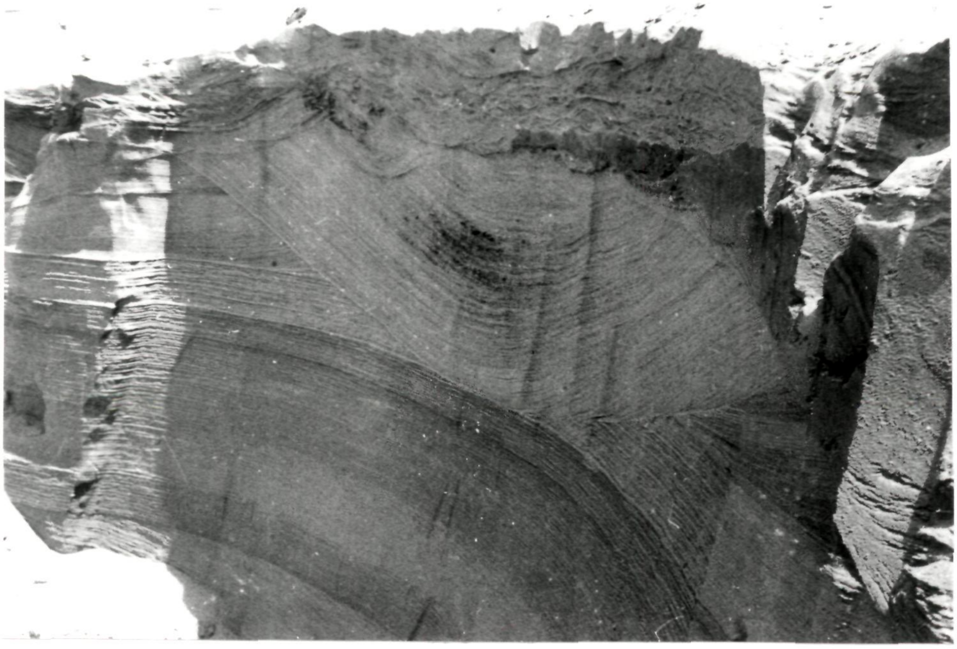


Fig. 17

Fig. 16. Lower part showing gravelly channel facies. Upper part shows massive mud facies.

Fig. 17 Sandy channel facies in which sediments are filled conforming the shape of the channel.

deposit (Rust, 1972, 1978; Miall, 1977; Reineck and Singh, 1980, p. 71). The scoured base suggests that the gravel was deposited by channellized, sediment-laden gravelly flows (Morison and Hein, 1987, p. 207). The grass roots are penetrated in them which indicate that the sequence after deposition was exposed for a longer period and provided opportunity to grow vegetation, which in turn submerged under water and the overlying massive sequence was deposited.

Sandy Channel Facies (Ss):

The lense shaped channel sand bodies were recorded and studied in trenches as well as on the exposed surfaces. In trenches, the width of channel sand bodies ranges from 2.25 m to 4 m and thickness 20 cm to 50 cm. However, on exposed surfaces the channel sand bodies were studied ranging in width from 35 cm to a meter, thickness upto 1.05 m and length upto about 10 m. Some channel bodies have erosional bases and flat tops, however, most of these are biconvex (Fig. 17 & 18). Generally channel sand bodies are overlain and underlain by ripple drift cross laminations. Some of these bodies are underlain by horizontal stratification. The facies is mostly comprised of coarse to fine sand, with occasional silt deposits. The channels are filled with sediments conforming the shape of the channel. At few places the channels show trough and planar cross-stratification.

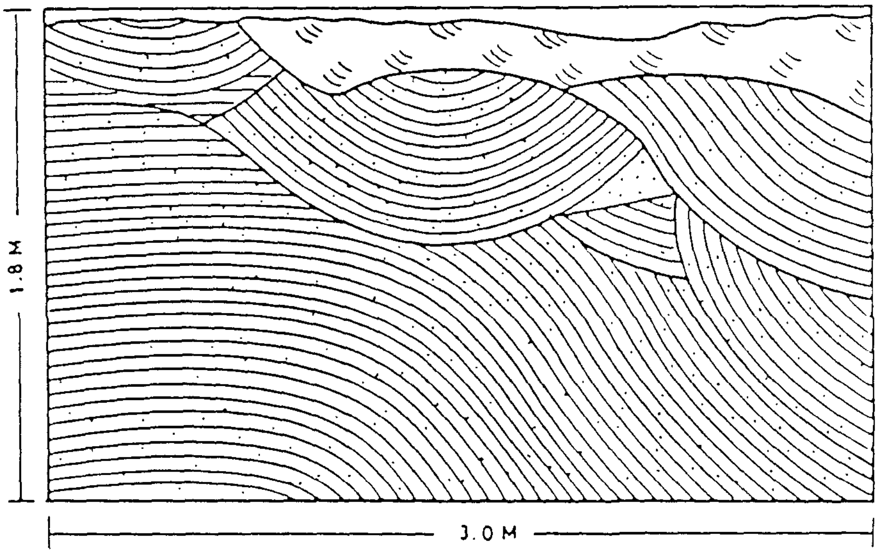


FIG. 18 LENSE-SHAPED CHANNEL SAND BODIES ARRANGED IN EN-ECHELON PATTERN

These channel sand bodies occur as isolated lenses and in enechelon pattern.

Interpretation:

Channels are filled by streams in partly subaerial position or by submerged currents. Channels filled with sediments conforming the shape of the channel evidently suggest a progressive decline in current competency filling the channels due to suspended load under submerged conditions (Reineck and Singh, 1980, p. 72). The occurrence of erosional scours, trough and planar cross-stratifications and concave upward base of individual channels are evidence of deposition by vertical aggradation (Moody-Stewart, 1966; Campbell, 1976; Collinson, 1978). The channel bodies which occur as multistory and multilateral deposits suggest frequent lateral shifting of sand bars in the multiple river channels. It seems that the scoured surfaces are produced due to sudden increase in current velocity, and subsequently filled in response to the decrease in current velocity (Kumar and Singh, 1978). The vertical change from parallel bedded to cross-stratified sand in the channel indicates fluctuations in velocity during flooding and suggests more than one peak surge of water during the flow (Mckee et al., 1967).

Trough Cross-Stratified Sandy Facies (St):

The individual units which are < 4 cm thick are described as small scale cross-stratifications and > 4 cm thick units as large scale cross-stratifications (Reineck and Singh, 1980, p. 98, 99). Trough cross-stratifications occur as solitary set and cosets. In vertical section parallel to current flow, troughs are well defined by shallow scours. The curvilinear foresets run parallel to the basal scoured surface. The fill of the troughs is either symmetrical or asymmetrical. In vertical section traces of foresets are commonly symmetrically curved and tangential to the underlying erosional surfaces (Fig. 19, 21a & b). The long axes of the scours are parallel to the local flow direction.

The large scale cross-stratifications in lower part of the sequence are comprised of coarse sand. Higher up in the sequence, the sand becomes fine and thin bedded characterised by small scale cross-stratifications. The thickness of the individual set of small scale trough cross-stratifications varies from 1.5 cm to 4 cm and large scale trough cross-stratified units range between 5 cm to 45 cm. The scale and grain size of the facies decrease in down stream direction.

Interpretation:

Trough cross-stratifications are formed by the migration of dunes (Collinson, 1970; Smith, 1971), megaripples

Fig. 19

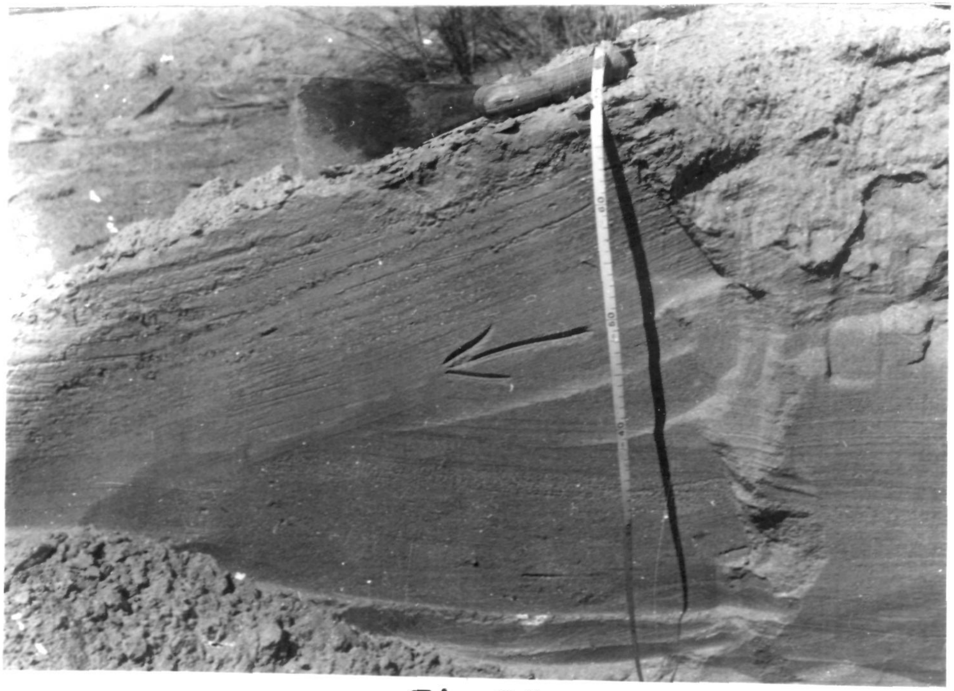
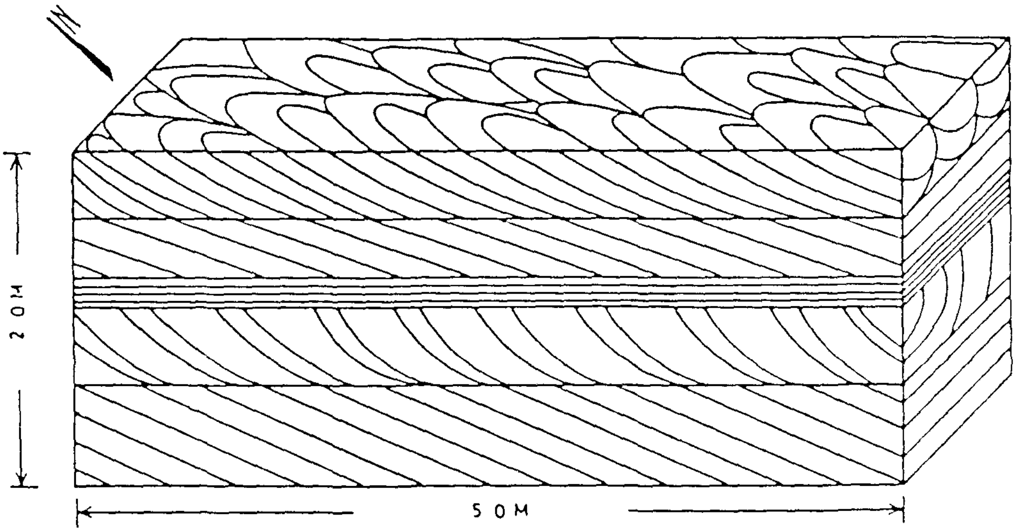


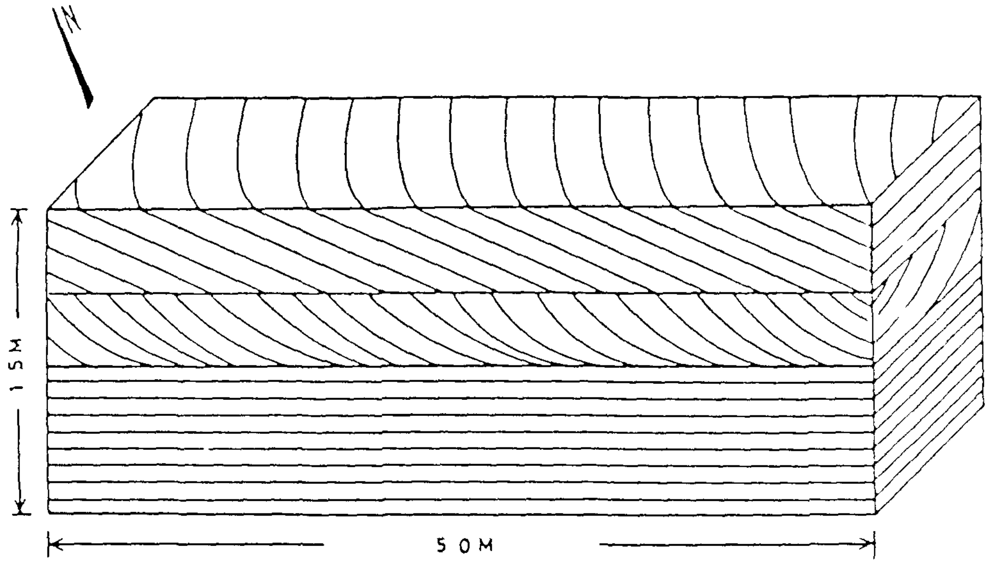
Fig. 20

Fig. 19. Trough cross-stratified sandy facies consisting coarse sand in the lower part and fine sand in the upper part. Middle part showing parallel laminated fine sand, silt and clay facies.

Fig.20. Planar cross-stratified sandy facies.



(a)



(b)

FIG 21 (a) SHOWING LARGE SCALE PLANAR AND TROUGH CROSS-STRATIFICATION AND PARALLEL LAMINATION
(b) SHOWING LARGE SCALE PLANAR AND TROUGH CROSS-STRATIFICATION AND HORIZONTAL STRATIFICATION

(Karcz, 1972; Singh and Kumar, 1974; Reineck and Singh, 1980, P. 102), lunate ripples (Allen, 1963; Desloges and Church 1987, p. 106). Aario (1971) described each trough filling due to down stream migration of ripples. Harms et al., (1982 described the formation of trough cross-stratification by the migration of three dimensional large ripples (dunes and mega ripples). Cosets of trough cross-stratification indicate unidirectional flow with appropriate range of depth and velocity to form three dimensional large ripples. The large scale cross-stratifications are interpreted as formed due to infilling of scours by migrating the sediments with lee face advancing dunes.

The trough cross-strata observed in the channel like bodies, are interpreted as sediment laden flood water scoured the channels and then filled them as flow power decreased (Fielding, 1986). It is interpreted the formation of small scale trough cross-stratification was due to the infilling of circular or elliptical shaped scours connected with migration of linguoid current ripples (Beck and Koster, 197[illegible]). The occurrence of this facies suggests that the processes of scouring and infilling of troughs were not penecontamporaneous.

Planar Cross-Stratified Sandy Facies (Sp):

Planar cross-strata occur as small scale and large scale in solitary sets and cosets (Fig. 20, 21a & b). The strata are overlain by trough cross-stratifications and horizontal stratifications. Large scale planar cross-stratifications are developed in lower part comprising coarse sand while in upper part small scale planar cross stratifications are developed in fine sand. The alternating coarse-fine foresets were also observed and show variation in thickness. The foresets having coarse sediments are thick while the foresets having fine sediments are thin. The large scale planar cross-stratified units range in thickness from 15 cm to 60 cm, in width upto 1 m and length upto 16 m. Small scale units range from 3 cm to 4 cm in thickness, few centimeters to 50 cm in width and length upto 7 m. The length of large scale foresets range between 12 cm to 80 cm and those of small scale foresets vary from 6 cm to 9 cm. The foresets of large scale units are inclined at 18° to 29° and of small units less than 18°. The scale and size of sediments of the facies decrease in down stream direction. The large scale planar cross-stratifications were also observed to inclined normal to the current direction. In vertical section the foresets are sharply truncated at top and bottom but some foresets are gently tangential against bottom.

Interpretation:

The large scale cross-strata showing inclination norma to the main flow are interpreted as the deposits of transverse or linguoid bars (Collinson, 1970; Smith, 1970, 1971; Casshyar and Kumar, 1987). The foresets consisting alternating coarse and fine sediments are the result of avalanching of sediments previously sorted by small bed forms on the bar surface upstream from the slip face (Smith, 1972). Thicker foresets resulted due to the larger parent bed forms and higher flow regime permits transport of coarser grains resulting grain size difference in the foresets. The cross-stratifications developed in transverse bars are the result of suspended load or the migration of sediments on the avalanche face at the margins of transverse bars. Miall (1985) described growth of foresets leading to the development to transverse bars when the bars covered by gradual waning flood events. Harms et al., (1982) described cross-stratification deposited by migrating two dimensional large ripples. Planar cross-stratification is characteristic of deposits that accumulate where sediment transported by moving water, which causes movement of sediment to decrease or to cease (Mckee et al., 1967).

The large scale planar cross-stratification developed in longitudinal bars are interpreted to be formed due to the migration of large straight crested sand sheets (some times by ripples and mega ripples) on the surface of the bar and slips down and deposited on the avalanche face of the bar. Small scale planar strata were deposited by sand sheets similar (but small) to those of large scale planar strata.

Ripple Drift Cross Laminated Sandy Facies (Sr):

The facies comprises very coarse sand in channel bars and very fine sand in bank deposits. Thickness of this facies ranges from 9 cm to 60 cm. The scale decreases vertically with grain size. The scale and size of sediments of the facies decreases in downstream. Mostly, the facies is overlain by horizontal laminations but at few places the small scale trough cross-stratifications also occur.

Two types of ripple laminae are observed - Ripple Laminae in phase (Fig. 22) and Ripple Laminae in drift (Fig.2 . In the case of ripple laminae in phase, both the stoss and lee side are preserved. The crest of one ripple lies directly above the crest of the other with a slight shift in the current direction. In the case of ripple laminae in drift, the crest has moved in the direction of current flow and laminae are not continuous. The stoss side of the ripple laminae in drift is partly or completely eroded. The angle of inclination ranges from 7° to 25°.

Fig. 22

Fig. 23

Fig. 22. Middle part (yellowish colour)showing ripple drift cross laminated sandy facies in which ripple laminae are in phase. Lower part showing convolute laminated facies developed in silt and clay.

Fig. 23. Large scale and small scale ripple drift cross laminated sandy facies in which ripple laminae are in drift.

Interpretation:

Ripple drift cross laminations are the result of forward migration and simultaneous upward growth of ripples. In sections, cut perpendicular to the direction of flow, foreset laminae show a tendency of climbing. If little sand is available in suspension the ripple laminae in drift are produced, with increase in supply of suspension load the ripple laminae in phase will be produced (Kumar and Singh 1978). Climbing ripples may be produced by straight crest, undulatory or small linguoid current ripples or even by wave ripples (Reineck and Singh, 1980 p. 110).

The ripple drift cross laminations in which laminae are in phase are interpreted as the result of abundance supply of sediments in suspension, no erosion on stoss side takes place and laminae in phase are completely burried and preserved. The ripple laminae in phase are produced only when angle of climb is greater than the stoss side slope. The ripple drift cross laminations marked with high angles of climb, indicate high rate of deposition (mainly from suspension) which may be resulted from deceleration of flow, with a corresponding increase in sedimentation as occurs during waning stages of floods (Lindholm, 1987, p.20). The ripple drift cross laminations, in which ripple laminae are in drift are the result of continuous supply of sediments. If the angle of climb is less than the stoss side slope, erosion occurs and only fore-sets are preserved. Ripple drift cross laminations indicate an environment of abundance sediments being deposited from suspension and water moving in a slow phase of the lower flow regime (Mckee, 1966). It is interpreted that ripple drift cross laminations develop during the waning phase of large flood, and represent movement of water far below that of strong flood waters. Ripple drift cross laminations demonstrate a high rate of vertical accretion (Collinson, 1986).

Convolute Laminated Fine Sand Silt and Clay Facies (Fc):

Convolute laminations are commonly observed in sediments which comprised fine sand, silt and clay. Internally it appears as folded layers, usually with broad synclines and narrow anticlines. Convolute laminations are frequently developed in bank (levee) deposits but also developed in braid bars. The degree of deformation gradually decreases downward to undeformed state. The folds are either symmetrical or weakly to moderately asymmetrical with overturned limb as reported by Chakrabarti (1977) from braid bars of Ganga River. Keeping this in view convolute laminations are divisible into two types - Type A and Type B.

Type A:

In this type the troughs or synclines are broad, separated by sharp anticlines (Fig. 22). The laminae are intensely folded being thinner in the crest and thicker in the troughs. At few places convolute laminations laterally change into ripple drift cross laminations (Fig. 35a). This type of convolute laminations generally range in thickness from 5 cm to 22 cm. Laterally they extend upto 2 m to 2.5 m. Generally they are overlain and underlain by parallel laminations or ripple drift cross laminations.

Type B:

In the type B the axial planes of folds are inclined in the down current direction. The angle of inclination of axial planes varies in the same sedimentation unit. The intensity of deformation increases upward in the same sedimentation unit. The thickness of type B convolute laminations varies from 6 cm to 16 cm and laterally persist upto 2 m. Generally they are underlain by ripple drift cross laminations or small scale trough cross-stratification. Occasionally, type B convolute laminations are overlain by type A convolute laminations.

Interpretation:

'Liquefaction' associated with rapid deposition, is generally considered to be an important mechanism for the development of convolute laminations. Other factors that have been suggested by Lindholm (1987, p.34) include: (1) shear caused by fluid flow acting on the sediment surface, (2) expulsion of pore water,(3) loading contemporaneous in deposition, and (4) lateral laminar flow of liquefied beds. William and Rust (1969) described 'quick' thixotropic property as the diagonostic character for the development of convolute laminations.

Type A convolute laminations are interpreted as the result of hydroplasticity difference of the underlying and overlying layers, the bed above gets unstable and breaks down into big and small fragments which try to sink into hydro plastic layer below by normal gravitation, and remain permanently traped. Pore fluid expulsion generated during loading of overlying sediments is the other mechanism due to which the type A convolute laminations were resulted (Morison and Hein, 1987, p. 211).

The convolute laminations of type B having inclined axial planes in the down current direction were formed during high flow through partial liquefaction and deformation of water saturated sediment under the influence of lateral shearing (Mckee et al., 1962; Casshyap and Kumar, 1987).

Parallel Laminated Fine Sand, Silt and Clay Facies (Fl): In parallel laminated facies, each laminae is parallel to the lower set boundary (Harms and Fahnestock, 1965). The laminations show variation in colour (alternating dark and light) and texture and are comprised of fine sand, silt and clay (Fig. 19 & 21a). The thickness of each laminae ranges in between 1 mm to 1 cm. However, the laminae having 2 mm to 3 mm thickness are very common. The parallel laminations range in thickness from 2 cm to 25 cm and are persistant laterally for few meters. The laminations are devoid of any kind of undulations. They are developed both in bank deposits and channel bars, but most frequently observed in bank deposits. They are overlain by ripple drift cross laminations or trough cross-stratifications.

Interpretation:

The laminations developed in fine sand are interpreted as the product of flash floods under upper flow regime conditions (William and Rust, 1969; Miall, 1977, 1984b, 1985; Rust, 1978b; Tunbridge, 1981, 1984; Sneh, 1983). The parallel laminations overlain by ripple drift cross laminations and trough cross-stratifications indicate waning flow conditions at the end of flood event (Tunbridge, 1981; Miall, 1985). Under upper flow regime conditions ripples and dunes are destroyed and water surface is smooth like glassy appearance (Collinson and Thompson, 1982 p. 97).

The laminations in silt and clay were developed under lower flow regime when the competency of flowing water to transport the sediment was reduced. The laminations which comprise large quantity of mica or silt and clay may be interpreted as the product of suspension conditions while the laminations comprising mica free fine sand are the product of high velocity currents and low depth (Collinson, 1986).

Massive Sandy facies (Sm) and massive Silt and Clay Facies(Fm):

Massive units are described as the units lacking visible internal stratification (Fig.16 & 24). These units are observed in both channel bars and bank deposits. Lithologically, massive units developed in channel bars comprise sand, and those developed in bank deposits comprise mostly silt and clay. The thickness of individual units ranges from 17 cm to 85 cm, and extend laterally for few meters. Concretions are present in the massive units developed in the channel bars. The sediments exposed for longer time are marked by brownish colour or reddish patches. Some units are marked by biogenic activities. The thickness of Fm facies increases in down current direction.

Interpretation:

Fielding (1986) interpreted the massive units as the result of rapid sediment dumping from high energy flow. Massive units comprised of sand may be interpreted as the result of sediment transportation in planar sheets under

Fig. 24

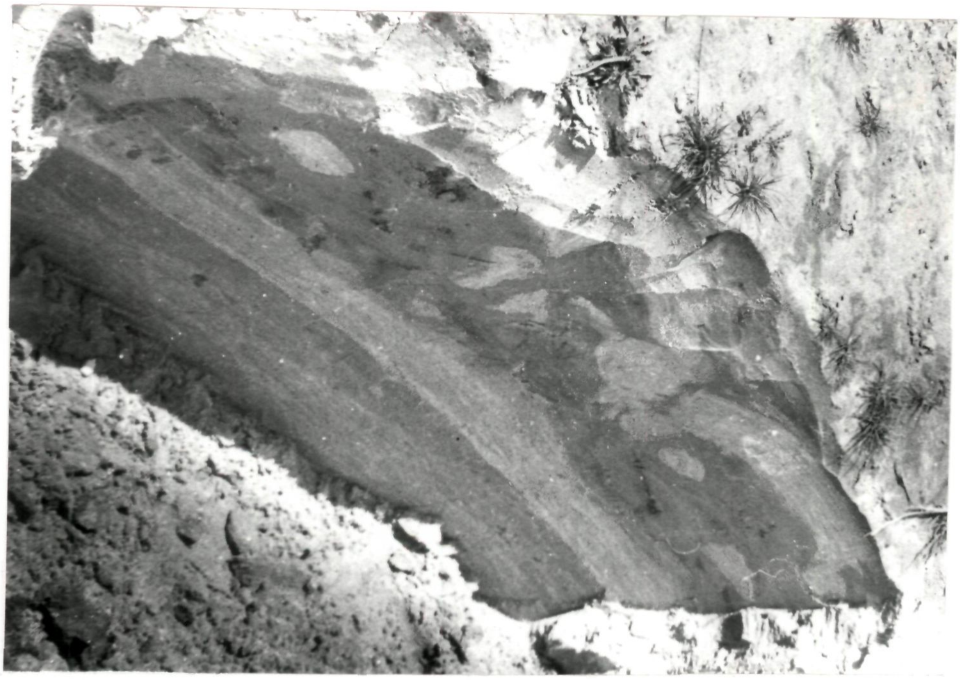


Fig. 25

Fig. 24. Upper part showing sandy massive facies.

Fig. 25. Lenticular sandy facies. Sand lenticles are embedded in mud.

very high energy conditions (Rust, 1972b; Casshyap and Kumar, 1987). Lindholm (1987, p.28) described massive units formed by certain sedimentary gravity flows which lack a mechanism to produce primary structures or the structures are destroyed by upward movement of pore water or by bioturbation. Mottled nature and concretions present in the sandy massive units clearly indicate the product of post depositional activities which destroyed primary stratification. Silt and clayey massive units are interpreted as having formed by heavily laden water current during waning periods of flood stage. Similar interpretation of massive units having fine sand and silt representing rapid deposition as suspension fallout from possible flood flows are provided by Morison and Hein (1987, p. 211).

Horizontal Stratified Sandy Facies (Sh):

As the term indicates the lower bounding surfaces of horizontal stratifications are horizontal or nearly so (Fig. 21b). Thickness of each stratified layer ranges from few cm to 7 cm. Lithologically, horizontal stratification comprises coarse to fine sand. Stratification is visible due to difference in grain size, variation in mica content, mineral contents and colour variation in stratified layers.

Interpretation:

Horizontal stratified facies can develop under two quite different conditions, in shallow water and during flood stage (Miall, 1977). Coleman (1969) interpreted the horizontal stratification as having formed by rapidly migrating trains of exceptionally small bed forms. Horizontal stratification comprised of coarse sand may be interpreted as indicating transportation in planar sheets under high energy conditions (Casshyap and Kumar, 1987; Desloges and Church, 1987). Similar interpretations were given by Harms and Fannestock (1965), Mckee et al. (1967). Horizontal stratifications comprised of fine sand have been developed by deposition of sediment under suspension during waning flood.

Lenticular Sandy Facies (Sl):

This facies is marked by the presence of discontinuous and isolated ripples or sand lenses both vertically or laterally (Fig. 25). This facies is developed in bank deposits. Both lenticular bedding with connected sand lenses and isolated sand lenses have been observed. The thickness of the set comprising the laminations of silt and clay (mud) ranges from 5 cm to 20 cm. Each laminae of mud is 1 mm to 2 mm thick. The height of the ripple ranges from 1 cm to 5 cm and in length the isolated ripple varies from 16 cm to 25 cm.

Interpretation:

The development of lenticular bedding requires conditions of current or wave action depositing the sand alternating with slack water conditions when mud is deposited (Reineck, 1960a,b). The sand lenses are made up of foreset laminae of current ripples. When the ripples migrate (with a zero angle of climb) a muddy substrate, and supply of sand or silt is limited, the isolated ripple trains as lenticular bedding may be preserved (Lindholm, 1987, p. 21). Therefore it is interpreted that the lenticular laminae were developed due to fluctuations in the current velocity. Unsteady sediment transport associated with the turbulent bursting process formed the lenticular laminae (Bridge and Best, 1988). Under slack water conditions only fine silt and clay (mud) was deposited. The deposition of silt and clay was interrupted by sudden increase in velocity responsible for the supply of sand in the form of incompletely developed ripples, and preserved by next mud layer under slack water conditions.

CHAPTER III

GRAIN SIZE ANALYSIS

GENERAL REMARKS:

Grain size is an important tool to understand the sedimentary processes and environments of deposition. But the difficulty arises when the grain size distribution shows the similar parameters of different environments of deposition. Even then the grain size distributions can be used to understand the sedimentary processes and environments of deposition. During last few years, the environment of deposition has been determined on the basis of grain size distribution (Folk and Ward, 1957; Mason and Folk, 1958; Harris, 1959; and Friedman, 1961, 1967). These workers have used the statistical measures such as mean, standard deviation, skewness and kurtosis to separate beach, dune, aeolian flat, and fluvial environments. This approach has been moderately successful in modern environments but less successful in interpreting the genesis of ancient sediments.

Doeglas (1946) observed that (1) grain size distributions are mixtures of two or more component distributions or populations, and that (2) these distributions were produced by varying transport conditions.Inman (1949)recognised three fundamental modes of transport,surface creep,saltation, and suspension.Relation of grain size distributions to depositional processes is given by Moss (1962, 1963). Inman (1949) distinguished three populations (surface creep, saltation, and suspension) on the basis of shape and size of the particles. These processes were applied by Moss (1962, 1963) using the shape and size of the grain and distinguished subpopulations.

Moss (1963, p.340) described that fine particles transported in suspension usually have an upper size limit of about 0.07 to 0.1 mm, but occasionally may be coarser. Visher (1967a, 1967b) observed in the recent sediments that most sedimentary laminae contain grain size an order of 0.1 mm or smaller size fraction, which are directly deposited from the suspension mode of transport. Fuller (1961, p.260) suggested that the break between saltation and rolling populations in many instances occurred near 2 phi, or the point of junction between the Impact and Stokes laws of particle settling. This is the size where inertial forces cause rolling or sliding of particles rather than saltation. The coarse straight line segment represents traction load or surface creep.

Methods of Study:

Forty one representative samples were selected for grain size analysis. Grain size analysis was carried out mechanically using $\sqrt{2}$ grade scale of Wentworth (1922) following the standard method of seiving . Hundred grams of sediments were taken for each sample, to avoid both irrational class limits and mid point and also to simplify the statistical computation in Phi (Φ) scale. The data were grouped into Φ size classes with interval of 0.5Φ (Table I).

Cumulative curves were plotted on log probability paper. Vishar (1969) studied the grain size distribution and recognised three distinct subpopulations (surface creep, saltation, suspension) represented by straight line segments on the log probability curve. Percentage of each subpopulation was determined from the curve. Sorting of each subpopulation was evaluated on the basis of slope of the straight line segment representing the subpopulation. The arbitrary angular limits of steepness of the curve suggested by Visher (1969) were adopted here as a measure of sorting.

$<50°$	Poor sorting
50° - 60°	Fair sorting
60° - 70°	Good sorting
$>70°$	Excellent sorting

Truncation points at the coarser and finer ends of each subpopulation segment were determined. All the above determined characteristics of subpopulations of grain size distribution are summarised in table (II & III).

The grain size distribution was grouped broadly into three types of probability plots mainly on the basis of number

Table I. Size Frequency Distribution (Percent) of Ganga sand.

S.No.	Quantity taken in gms.	Diameter in Phi (Ø) scale											
		-1.5 to -1.0	-1.0 to -0.5	-0.5 to 0.0	0.0 to +0.5	+0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	>4.0
						Hardwar							
4	100	0.326	0.287	0.352	0.571	9.854	15.634	41.423	24.635	5.396	0.788	0.725	-
5	100	0.690	0.140	1.237	2.330	19.808	14.051	28.210	25.216	6.713	0.901	0.601	-
6	100	18.637	0.937	5.636	1.346	4.485	5.667	11.992	7.633	5.151	14.678	23.837	-
7	100					0.150	0.470	5.100	23.500	49.410	8.300	8.150	4.425
8	100					0.080	0.320	3.000	9.730	49.010	12.570	15.310	9.980
9	100					0.310	0.240	1.930	4.130	43.340	12.800	20.440	16.800
10	100					0.350	1.700	7.750	13.650	49.500	10.030	11.300	5.720
11	100					0.610	2.950	1.850	13.880	48.050	8.200	9.640	4.750
12	100					1.610	4.640	20.500	31.700	35.250	3.400	2.100	0.800
						Sherpur							
13	100					2.080	14.000	44.300	18.550	17.530	1.480	1.250	0.840
14	100					0.030	0.130	1.785	10.430	50.180	9.825	13.100	14.520
15	100					0.240	0.470	2.900	6.330	51.170	9.950	13.920	15.020
16a	100					0.285	0.670	8.470	35.445	48.500	3.030	2.470	1.130
16b	100					0.015	0.100	0.830	1.260	17.300	5.900	24.670	49.950
						Garhmukteshar							
18	100					0.990	1.100	9.160	35.400	49.400	2.550	1.150	0.300
19	100					0.050	0.850	37.430	35.800	23.800	1.040	0.660	0.380
20	100					0.000	0.150	5.630	31.560	52.600	4.600	3.910	1.550
21	100					3.000	8.070	25.100	28.300	30.320	1.030	1.400	0.800
22	100					0.190	1.800	31.580	34.950	15.680	3.450	7.550	4.700
23	100					0.140	0.250	1.000	1.700	11.750	12.560	34.300	38.700
						Rajghat							
24	100					0.325	5.400	52.000	25.200	12.000	0.960	2.350	1.760
25	100					0.730	5.400	45.650	34.550	13.030	0.350	0.280	0
26	100					0.375	1.670	17.480	28.655	40.050	4.950	5.300	1.720
27	100					0.015	0.240	0.900	1.280	10.720	5.100	28.020	43.720
28	100					0.325	5.400	52.000	25.200	12.000	0.960	2.350	1.760
29	100					0	0.050	1.350	2.480	8.650	5.450	31.170	50.840
30	100					0.060	0.270	6.350	38.920	51.530	1.460	0.910	0.400
						Kachhla							
36	100					0.040	0.060	0.345	4.976	56.681	21.220	10.920	5.757
37	100					0.010	0.025	0.507	16.053	63.070	12.105	5.753	2.466
38a	100					0.025	0.048	0.832	37.395	53.345	5.477	1.744	1.230
38b	100					0.029	0.080	2.278	57.287	36.398	2.272	1.122	0.532
39	100					0.012	0.025	0.142	2.708	44.732	23.040	10.702	9.758
40	100					0.016	0.035	0.670	34.835	59.793	3.208	1.002	0.440
41	100					0.440	0.758	7.435	42.380	36.630	2.980	3.787	5.589
42	100					0.485	0.470	2.103	16.760	54.153	13.330	7.422	5.274
43	100					0.023	0.029	0.162	1.424	16.920	15.548	19.977	45.916
44a	100					0.287	0.691	6.102	30.169	51.883	7.460	2.283	1.124
44b	100					0.009	0.008	0.094	0.790	21.910	21.760	19.700	35.728
45	100					1.049	3.295	25.263	39.920	25.970	2.877	1.032	1.595
46	100					2.862	4.510	20.032	47.535	23.185	0.983	0.405	0.487
47	100					2.595	4.283	28.922	49.608	11.874	1.088	0.680	0.940

Table II. Size frequency Percentile Parameters of Ganga Sand.

Sample No.	Percentile size in Phi (Ø) unit							Folk and Wards parameters			
	Ø5	Ø16	Ø25	Ø50	Ø75	Ø84	Ø95	Mean (Mz)	Sorting (σI)	Skewness (SK_I)	Kurtosis (K_G)
					Hardwar						
4.	0.77	1.18	1.42	1.78	2.15	2.30	2.80	1.75	0.58	-0.03	1.13
5.	0.52	0.82	1.03	1.70	2.09	2.25	2.70	1.59	0.68	-0.15	0.84
6.	-1.00	0.50	0.69	1.20	1.87	2.18	2.60	1.14	1.07	-0.28	1.25
7.	2.00	2.30	2.45	2.70	2.90	3.30	4.00	2.76	0.55	+0.25	1.82
8.	2.15	2.60	2.75	2.85	3.50	3.80	4.40	3.08	0.64	+0.49	0.87
9.	2.40	2.65	2.70	3.00	3.80	4.25	4.35	3.30	0.69	+0.47	0.72
10.	1.80	2.30	2.50	2.70	3.10	3.60	4.10	2.86	0.67	+0.30	1.57
11.	1.60	2.00	2.35	2.70	2.90	3.30	4.20	2.66	0.71	+0.03	1.93
12.	1.40	1.80	2.00	2.40	2.60	2.70	3.20	2.30	0.49	-0.05	1.27
					Sherpur						
13.	1.20	1.50	1.65	1.90	2.40	2.60	2.90	2.00	0.53	+0.22	0.92
14.	2.25	2.55	2.65	2.80	3.60	3.95	4.60	3.11	0.70	+0.53	1.01
15.	2.20	2.60	2.65	2.90	3.70	4.00	4.60	3.16	0.71	+0.49	0.93
16a	1.85	2.70	2.30	2.56	2.65	2.70	3.70	2.48	0.32	-0.21	1.58
16b	2.60	2.90	3.45	4.00	4.40	4.60	5.00	3.83	0.78	-0.23	1.32
					Garhmukteshar						
18.	1.30	2.10	2.30	2.50	2.65	2.70	2.90	2.43	0.39	-0.41	1.87
19.	1.70	1.80	1.90	2.15	2.50	2.70	2.80	2.21	0.39	-0.80	0.66
20.	2.00	2.20	2.35	2.60	2.80	2.90	3.55	2.56	0.40	+0.04	1.41
21.	1.20	1.60	1.80	2.30	2.60	2.70	3.20	2.00	0.57	-0.33	1.02
22.	1.60	1.80	1.90	2.20	2.70	3.00	4.00	2.33	0.66	+0.41	1.22
23.	1.60	3.10	3.45	3.90	4.25	4.00	4.90	3.80	0.82	-0.32	1.17
					Rajghat						
24.	1.50	1.60	1.70	1.90	2.30	2.55	3.10	2.00	0.47	+0.43	1.09
25.	1.50	1.75	1.80	2.00	2.40	2.50	2.60	2.08	0.35	+0.21	1.37
26.	1.60	1.95	2.10	2.55	2.80	2.85	3.65	2.45	0.35	-0.23	0.82
27.	2.70	3.40	3.65	4.10	4.50	4.70	5.10	4.00	0,68	-0.12	1.15
28.	2.50	2.70	2.80	3.70	4.10	4.30	4.75	3.56	0.74	-0.45	0.71
29.	2.65	3.30	3.60	4.00	4.45	4.60	5.10	3.96	0.69	-0.68	1.18
30.	2.00	2.20	2.35	2.50	2.60	2.70	2.80	2.46	0.24	-0.26	1.63
					Kachhla						
36.	2.45	2.70	2.75	2.90	3.75	3.55	4.10	3.05	0.46	+0.49	0.67
37.	2.15	2.50	2.55	2.70	2.95	3.20	3.75	2.80	0.41	+0.37	1.69
38a	2.10	2.25	2.35	2.55	2.70	2.90	3.25	2.56	0.33	+0.14	0.85
38b	2.05	2.10	2.15	2.40	2.60	2.75	3.90	2.41	0.44	+0.34	1.68
39.	2.55	2.65	2.75	3.05	3.60	3.80	4.20	3.16	0.53	+0.19	0.79
40.	2.10	2.25	2.35	2.60	2.80	2.85	3.00	2.56	0.28	-0.13	0.81
41.	1.80	2.10	2.20	2.45	2.70	2.90	4.05	2.48	0.54	+0.27	1.84
42.	2.10	2.4	2.50	2.75	3.10	3.40	4.05	2.85	0.54	+0.31	1.32
43.	2.60	2.95	3.25	3.90	4.20	4.30	4.45	3.71	0.61	-0.40	0.79
44a.	1.90	2.20	2.35	2.65	2.80	2.90	3.50	2.58	0.41	-0.11	1.45
44b	2.60	2.85	3.05	3.15	4.10	4.20	4.35	3.40	0.60	+0.46	0.68
45.	1.55	1.70	1.85	2.25	2.60	2.75	3.00	2.23	0.48	-0.01	0.79
46.	1.30	1.70	1.85	2.15	2.40	2.45	2.90	2.10	0.42	-0.06	1.19
47.	1.25	1.80	1.90	2.20	2.50	2.70	2.90	2.23	0.47	-0.02	1.12

Table III. Grain size parameters of subpopulations in individual sample.

C.T = Coarse Truncation Point

F.T = Fine Truncation Point

Sample Number	Truncation Population					Saltation Population					Suspention population				
	Percent	Angle	Sorting	C.T	F.T	Percent	Angle	Sorting	C.T	F.T	Percent	Angle	Sorting	C.T	F.T
4.	1.8	26	Poor	-1.0	0.55	96.6	96	Good	0.55	3.0	1.6	55	Fair	3.0	4.[illegible]
5.	4.0	46	Poor	-0.5	0.5	92.0	66	Good	0.5	3.0	2.0	46	Poor	3.0	4.0
6.	15.0	36	Poor	-1.0	0.0	83.0	54	Fail	0.0	3.5	1.4	39	Poor	3.25	4.0
7.	0.6	56	Fair	1.0	1.5	77.4	71	Excellent	1.5	3.15	22.0	56	Fair	3.15	4.5
8.	0.45	55	Fair	1.0	1.5	71.55	55	Fair	1.5	3.28	38.0	55	Fair	3.28	4.[illegible]
9.	0.55	32	Poor	1.0	1.5	50.45	52	Fair	1.5	3.0	49.0	53	Fair	3.0	4.[illegible]
10.	2.0	64	Good	1.0	1.5	72.o	69	Good	1.5	3.05	26.0	53	Fair	3.05	4.[illegible]
11.	3.5	65	Good	1.0	1.55	75.5	74	Excellent	1.5	3.0	21.0	52	Fair	3.0	4.[illegible]
12.	6.5	66	Good	1.0	1.48	89.5	66	Good	1.48	3.25	4.0	44	Poor	3.25	4.[illegible]
13.	-	-	-	-	-	96.0	71	Excellent	1.0	3.05	4.0	41	Fair	[illegible]	4.[illegible]
14.	0.5	58	Fair	1.0	1.84	63.5	66	Good	1.84	3.04	36.0	48	Poor	[illegible]04	4.[illegible]
15.	0.6	42	Poor	1.0	1.5	61.4	75	Excellent	1.5	3.05	38.0	46	Poor	3.05	4.[illegible]
16a.	1.2	52	Fair	1.0	1.6	93.0	74	Excellent	1.6	3.1	5.8	52	Fair	3.1	4.[illegible]
16b.	1.0	53	Fair	1.0	2.0	19.0	75	Excellent	2.5	3.0	80.0	52	Fair	[illegible]0	4.5
18.	3.0	46	Poor	1.0	1.8	92.8	81	Excellent	1.8	3.05	5.2	52	Fair	[illegible]05	4.[illegible]
19.	0.9	75	Excellent	1.0	1.5	41.1	72	Excellent	1.5	3.25	58.0	64	Good	3.2	4.5
20.	-	-	-	-	-	89.5	72	Excellent	1.5	3.0	10.5	58	Fair	3.0	4.[illegible]
21.	-	-	-	-	-	97.5	75	Excellent	1.0	3.5	2.5	76	Excellent	3.5	4.[illegible]
22.	2.0	57	Fair	1.0	1.5	93.0	74	Excellent	1.5	3.05	5.0	42	Poor	3.05	4.[illegible]
23.	3.0	49	Poor	1.0	2.5	11.0	68	Good	2.5	3.0	86.0	62	Good	3.0	4.5
24.	1.3	65	Good	1.0	1.35	93.5	80	Excellent	1.35	3.0	12.0	36	Poor	3.0	4.5
25.	6.0	62	Good	1.0	1.5	93.2	76	Excellent	1.5	3.05	0.8	45	Poor	3.05	4.[illegible]
26.	-	-	-	-	-	88.0	70	Excellent	1.0	3.05	12.0	56	Fair	3.05	4.5
27.	-	-	-	-	-	27.0	69	Good	1.0	3.15	73.0	54	Fair	3.15	4.[illegible]
28.	1.3	65	Good	1.0	1.35	93.7	80	Excellent	1.35	3.0	12.0	36	Poor	3.0	4.[illegible]
29.	12.2	69	Good	1.5	3.0	6.8	36	Poor	3.0	3.5	81.0	73	Excellent	3.3	4.[illegible]
30	0.3	56	Fair	1.0	1.5	98.0	76	Excellent	1.6	3.32	1.7	47	Poor	3.3	4.[illegible]
36	0.4	47	Poor	1.0	2.0	61.6	72	Excellent	2.0	3.07	36.0	67	Good	3.07	4.5
37	0.04	29	Poor	1.0	1.7	79.96	73	Excellent	1.7	3.04	20.0	60	Good	3.04	4.5
38a.	0.07	38	Poor	1.0	1.52	91.93	77	Excellent	1.52	3.05	8.0	52	Fair	3.05	4.5
38b.	0.1	46	Poor	1.0	1.5	95.9	78	Excellent	1.5	3.02	6.0	49	Poor	3.02	4.5
39	0.05	29	Poor	1.0	1.8	53.95	71	Excellent	1.8	3.13	46.0	68	Good	3.13	4.5
40	0.7	66	Good	1.0	1.98	94.3	80	Excellent	1.98	3.0	5.0	53	Fair	3.0	4.[illegible]
41.	1.4	38	Poor	1.0	1.88	72.6	79	Excellent	1.88	3.05	26.0	73	Poor	[illegible]	4
42	1.1	44	Poor	1.0	1.5	89.4	78	Excellent	1.5	3.01	9.5	50	Fair	3.01	4
43	0.2	48	Poor	1.0	2.0	20.0	71	Excellent	2.0	3.0	79.0	54	Fair	3.0	4.5
44a.	1.5	52	Fair	1.0	1.73	89.0	71	Excellent	1.73	3.05	9.5	66	Good	3.05	4.5
44b.	0.9	67	Good	1.5	2.5	22.1	78	Excellent	2.5	3.0	77.0	58	Fair	3.0	4.5
45.	4.5	59	Fair	1.0	1.5	91.5	74	Excellent	1.5	3.0	4.5	53	Fair	3.0	4.5
46.	7.5	57	Fair	1.0	1.49	91.4	74	Excellent	1.49	3.0	2.4	38	Poor	3.0	4.5
47.	5.5	55	Fair	1.0	1.4	91.5	73	Excellent	1.4	3.0	3.0	37	Poor	3.0	4.5

of subpopulations and their percentage and sorting. Type I, plot shows one inflection point between saltation and suspension loads; type II, exhibits two inflection points between traction and saltation, and saltation and suspension loads; and type III, with three inflection points recognised two saltation subpopulations herein called subpopulation A & B.

Several methods and scales for the estimation of roundness of detrital grains are available. But in the present study the method developed by Waskom (1958) is followed. It consists of assigning individual grains to appropriate Powers classes. Roundness estimations were made from the mounted slides, and in order to ensure regular traverse, the point counting technique described by Chayes (1949) was used. Two hundred grains were treated in each mounted slide and the data were grouped into Powers (1953) roundness classes. Thirty one samples were analysed and the arithmatic mean roundness for each sample was computed following Krumbein and Pettijohn (1938). The results are listed in table (IV).

For sphericity, long, intermediate and short axes of gravels were measured directly and values were calculated with the help of formula developed by Sneed and Folk(1958). The sphericity values are listed in the table (V).

Table IV. Roundness date of detritel grains in Ganga sand.

Locality	Sample No.	GRADE																		Mean roundness	
		Very angular			Angular			Subangular			Subrounded			Rounded			Well rounded				
		P	n	Pxn	P	n	Pxn	P	n	pxn	P	n	Pxn	P	n	Pxn	P	n	Pxn	Ma= Pxn/100	
Hardwar	4.	0.14	8	1.21	0.21	51	10.71	0.30	29	8.70	0.41	10	4.10	0.59	2	1.86	0.84	-	-	0.2490	Angular
	5.	0.14	31	4.34	0.21	92	19.32	0.30	54	16.20	0.41	20	8.20	0.59	3	1.77	0.84	-	-	0.2581	Angular
	6.	0.14	2	0.28	0.21	14	2.94	0.30	40	12.00	0.41	34	13.94	0.59	10	5.90	0.84	-	-	0.3506	Subangular
	7.	0.14	4	0.56	0.21	21	4.41	0.30	34	10.20	0.41	31	12.71	0.59	8	4.72	0.84	2	1.68	0.3428	Subangular
	8.	0.41	7	0.98	0.21	42	8.82	0.30	85	25.50	0.41	50	20.50	0.59	15	8.85	0.84	1	0.84	0.3270	Subangular
	9.	0.14	8	1.12	0.21	27	5.67	0.30	32	9.60	0.41	22	9.02	0.59	8	4.72	0.84	3	2.52	0.3265	Subangular
	10.	0.14	4	0.56	0.21	23	4.83	0.30	42	12.90	0.41	23	9.43	0.59	6	3.54	0.84	1	0.84	0.3210	Subangular
	11.	0.14	-	-	0.21	28	5.80	0.30	40	12.00	0.41	20	8.20	0.59	11	6.49	0.84	1	0.84	0.3341	Subangular
	12.	0.14	1	0.14	0.21	16	3.36	0.30	34	10.20	0.41	34	13.94	0.59	15	8.85	0.84	-	-	0.3649	Subrounded
Sherpur	13.	0.14	-	-	0.21	11	2.31	0.30	26	7.80	0.41	38	15.58	0.59	22	12.98	0.84	3	2.52	0.4119	Subrounded
	14.	0.14	2	0.28	0.21	12	2.52	0.30	30	9.00	0.41	44	18.04	0.59	12	7.08	0.84	-	-	0.3692	Subrounded
	15.	0.14	3	0.42	0.21	10	2.10	0.30	28	8.40	0.41	36	14.76	0.59	17	10.03	0.84	6	5.04	0.4111	Subrounded
	16a.	0.14	2	0.28	0.21	6	1.26	0.30	33	9.90	0.41	46	18.86	0.59	11	6.49	0.84	2	1.68	0.3847	Subrounded
	16b.	0.14	-	-	0.21	11	2.31	0.30	45	13.50	0.41	40	16.40	0.59	4	2.36	0.84	-	-	0.3457	Subrounded
	18.	0.14	-	-	0.21	8	1.68	0.30	40	12.00	0.41	44	18.04	0.59	8	4.72	0.84	-	-	0.3644	Subrounded
Garhmukteshar	19.	0.14	1	0.14	0.21	8	1.68	0.30	47	14.10	0.41	40	16.40	0.59	4	2.36	0.84	-	-	0.3470	Subangular
	20.	0.14	-	-	0.21	3	0.63	0.30	63	18.90	0.41	32	13.12	0.59	2	1.18	0.84	-	-	0.3383	Subangular
	21.	0.14	-	-	0.21	4	0.84	0.30	20	6.00	0.41	57	23.37	0.59	16	9.44	0.84	3	2.52	0.4217	Subrounded
	22.	0.14	-	-	0.21	9	0.89	0.30	44	13.20	0.41	37	15.17	0.59	10	5.90	0.84	-	-	0.3617	Subrounded
	23.	0.14	3	0.42	0.21	15	3.15	0.30	45	13.50	0.41	30	12.30	0.59	4	2.36	0.84	3	2.52	0.3425	Subangular
	24.	0.14	-	-	0.21	2	0.42	0.30	46	13.80	0.41	48	19.68	0.59	3	1.77	0.84	1	0.84	0.3651	Subrounded
Rajghat	25.	0.14	1	0.14	0.21	4	0.84	0.30	36	10.84	0.41	45	18.45	0.59	12	7.08	0.84	2	1.68	0.3899	Subrounded
	26.	0.14	-	-	0.21	3	0.63	0.30	38	11.40	0.41	41	16.81	0.59	15	8.85	0.84	3	2.52	0.4021	Subrounded
	27.	0.14	-	-	0.21	2	0.42	0.30	40	12.00	0.41	53	21.73	0.59	5	2.95	0.84	-	-	0.3710	Subrounded
	28.	0.14	-	-	0.21	8	1.68	0.30	33	9.90	0.41	50	20.50	0.59	7	4.13	0.84	2	1.68	0.3780	Subrounded
	29.	0.14	-	-	0.21	5	1.05	0.30	40	12.00	0.41	47	19.27	0.58	8	4.72	0.84	-	-	0.3704	Subrounded
Kachhla	30.	0.14	-	-	0.21	4	0.84	0.30	36	1.81	0.41	54	22.14	0.59	5	2.95	0.84	1	0.84	0.3758	Subrounded
	36.	0.14	-	-	0.21	2	0.42	0.30	39	11.7	0.41	54	22.14	0.59	5	2.95	0.84	-	-	0.3721	Subrounded
	37.	0.14	-	-	0.21	7	1.47	0.30	51	15.3	0.41	39	15.99	0.59	3	1.77	0.84	-	-	0.3453	Subangular
	38a.	0.14	-	-	0.21	1	0.21	0.30	41	12.3	0.41	54	22.14	0.59	3	1.77	0.84	1	0.84	0.3726	Subrounded
	38b.	0.14	-	0.14	0.21	3	0.63	0.30	42	12.6	0.41	51	20.91	0.59	2	1.18	0.84	1	0.84	0.3630	Subrounded

Table V. Sphericity Measurements of gravels.

Locality	Specimen Number	Clast Dimensions (in cm) Length (L)	Width (W)	Thickness (T)	Sphericity
Rishikesh	1.	4.1	2.3	1.2	0.5345 Moderate
	2.	3.7	2.1	1.2	0.5701 Moderate
	3.	4.3	2.9	1.2	0.4869 Moderate
	4.	3.5	2.8	2.2	0.7904 Moderate
	5.	3.5	2.3	1.2	0.5634 Moderate
	6.	3.0	2.8	1.8	0.7229 Moderate
	7.	3.4	2.4	1.5	0.6508 Moderate
	8.	2.4	2.1	1.2	0.6586 Moderate
	9.	3.0	1.3	1.0	0.6352 Moderate
	10.	2.5	1.8	1.2	0.6839 Moderate
	11.	3.1	2.2	1.0	0.5273 Moderate
	12.	3.2	2.1	1.1	0.5646 Moderate
	13.	2.8	2.1	1.9	0.8499 High
SaptRishi	14.	9.3	6.5	5.0	0.7450 Moderate
	15.	19.8	16.3	10.0	0.6766 Moderate
	16.	13.5	11.8	9.9	0.7524 Moderate
	17	8.6	8.7	5.8	0.7832 Moderate
	18.	7.4	4.1	2.1	0.5257 Moderate
	19	10.6	6.9	3.6	0.5616 Moderate
	20.	8.1	7.2	5.2	0.7739 Moderate
	21	5.9	4.5	3.1	0.7126 Moderate
	22	3.4	3.4	1.2	0.5200 Moderate
	23.	7.1	4.7	2.7	0.6022 Moderate
	24	4.9	3.9	3.2	0.8122 High
	25	5.1	3.8	2.2	0.6297 Moderate
	26	3.1	2.5	1.2	0.5706 Moderate
	27.	7.5	5.3	3.6	0.8820 High
	28	5.1	3.7	2.5	0.6918 Moderate
	29	8.6	7.1	4.1	0.6505 Moderate
	30	4.0	3.3	2.6	0.8000 Moderate
	31	6.2	4.9	3.3	0.7103 Moderate
	32	4.5	3.2	2.6	0.7771 Moderate
	33	8.6	6.3	5.3	0.8033 High
	34	3.4	1.7	1.1	0.5937 Moderate
	35	3.2	2.4	2.4	0.9066 High
	36	1.4	1.3	1.1	0.8227 High
	37	4.1	2.4	1.3	0.5558 Moderate
	38	10.6	6.5	4.1	0.6240 Moderate
	39	10.6	6.4	4.2	0.6182 Moderate
	40	24.5	8.3	3.5	0.3920 Low
	41	13.9	12.8	9.9	0.8129 High
	42	4.5	3.4	3.4	0.9107 High
Hardwar	43	3.3	2.8	2.3	0.8103 High
	44	3.4	2.2	2.0	0.8116 High
	45	4.1	2.4	1.9	0.7158 Moderate
	46	3.4	1.8	1.5	0.7163 Moderate
	47	5.6	2.0	1.8	0.6613 Moderate
	48.	3.6	2.9	1.7	0.6517 Moderate
	49	3.1	2.5	1.1	0.5384 Moderate
	50	3.1	2.1	1.7	0.7628 Moderate
	51.	3.4	1.0	2.0	0.7319 Moderate
	52	2.9	2.8	2.6	0.9407 High
	53	3.5	3.0	2.9	0.9286 High
	54	3.6	3.0	1.5	0.5928 Moderate
	55	4.1	2.7	1.0	0.4486 Moderate
	56.	3.9	2.9	2.5	0.8206 High
	57	2.6	2.1	1.7	0.8083 High
	58	2.6	2.1	1.9	0.8711 High
	59	2.3	1.8	1.7	0.8870 High
	60.	2.1	1.7	1.3	0.7793 Moderate
	61	2.5	1.7	1.2	0.6971 Moderate
	62	2.5	1.8	1.5	0.7937 Moderate
	63.	2.8	1.3	1.5	0.7392 Moderate
	64.	3.4	2.3	1.3	0.6001 Moderate
	65	2.7	2.2	1.7	0.7865 Moderate
	66	2.2	1.5	1.1	0.7157 Moderate
	67	3.3	2.6	2.2	0.8262 High
	68	1.9	1.1	1.1	0.8334 High
	69	1.6	1.6	1.3	0.8707 High
	70	2.7	2.5	1.7	0.7536 Moderate
	71.	3.4	2.8	1.0	0.4718 Moderate
	72	2.1	1.6	1.1	0.7114 Moderate
	73.	2.8	2.3	2.1	0.8814 High
	74.	3.0	1.9	1.1	0.5965 Moderate

Hardwar sediments:

The mean size of Ganga sediments at Hardwar varies from (Mz) 1.14 Φ to 3.3 Φ, well sorted to poorly sorted (σ_I) 0.49 to 1.07 Φ, strongly fine skewed to coarse skewed (SK_I) + 0.49 to - 0.28 and platykurtic to leptokurtic (K_G)0.72 to 1.8. Mean size is a function of the size range of available sediment and the amount of energy imparted to the sediment which depend on current velocity or turbulance of the transporting medium. Skewness and kurtosis were recognised as indicators of selective action of transporting agent (Krumbein and Pettijohn, 1938).

Of the 9 samples analysed from the Hardwar area, the cumulative curves of 7 samples show three sediment populations, traction, saltation and suspension, corresponding to, type II grain size distribution and remaining 2 samples, typeIII grains size distribution. In typeIII grain size distribution, saltation population in each sample consists two subpopulations (salatation A and saltation B; Fig. 26a & b). Particle size of inflection points of type II grain size distribution between traction and saltation population ranges from 0 Φ to 1.5 Φ, and for saltation and suspension populations from 3.0 Φ to 3.5 Φ. In type III grain size distribution, particle size of inflection points at coarser end, between traction and saltation A is 1.5 Φ and for those at finer

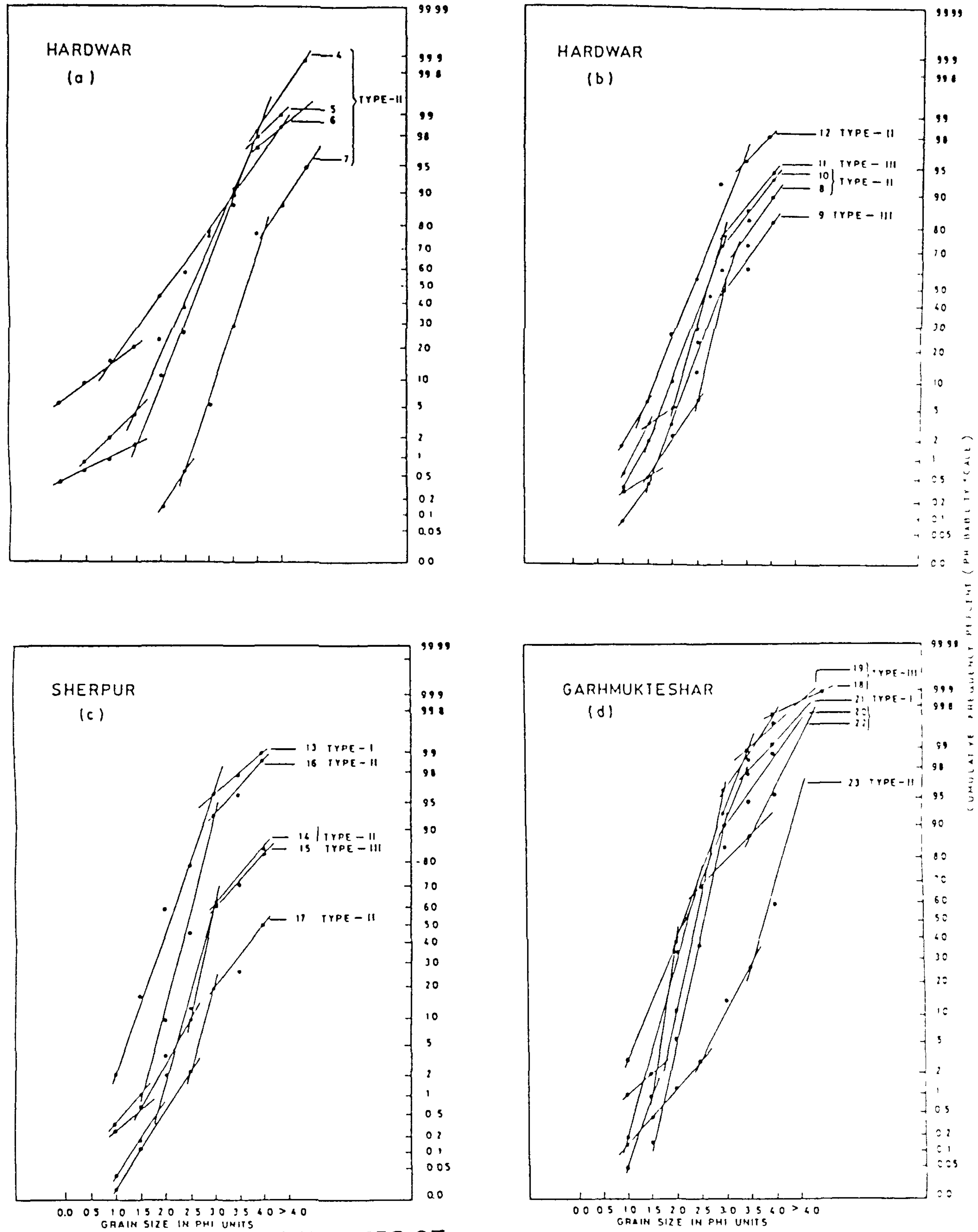


FIG. 26 LOG PROBABILITY PLOTS OF GRAIN SIZE DISTRIBUTION OF GANGA SAND

end between saltation B and suspension is 3.0 Φ, it is 1.5 Φ for inflection points between saltation A and B subpopulations.

Bulk of the sediment load is transported under the saltation process and constitutes about 50 to 92% by weight of the sample. Suspension fraction varies from 1.4 to 49%, whereas traction load is only less than 1 to 6.5%.

Sherpur sediments:

The mean size at Sherpur varies from (M_z) 2.0 Φ to 3.16 Φ, very well sorted to moderately well sorted (σ_I) 0.32 to 0.71 Φ, strongly fine skewed to coarse skewed (SK_I) + 0.53 to -0.23, and mesokurtic to very leptokurtic (K_G) 0.92 to 1.58.

Out of five, three plots of Sherpur sediments correspond to, type II grain size distribution yielding two inflection points; one, type III yielding three inflection points; and the other one, yielding only one inflection point (Fig.26c). The truncation points between traction and saltation populations of type II grain size distribution range from 1.5 Φ to 1.84 Φ in medium sand grade and for saltation and suspension from 3.04 Φ to 3.1 Φ in very fine sand grade. The particle size of inflection points of type III at coarser end between traction and saltation A, is 2.0 Φ, and for finer end between saltation B and suspension is 3.0 Φ. For type I, inflection point between saltation and suspension, is 3.05 Φ.

The saltation population 61.4 to 96% by weight constitutes the bulk of the load, suspension 3.5 to 38% but exceeding upto 80%, and traction material is sporadic 0.5 to 1.2%.

Garhmukteshar sediments:

Garhmukteshar sediments consist medium to very fine sand with mean size (M_z) varying from 2.0 to 3.8 Φ, well sorted to moderately well sorted (σ_I) 0.39 to 0.82 Φ, strongly fine skewed to strongly coarse skewed (SK_I) - 0.4 to -0.80, very platykurtic to leptokurtic (K_G) 0.60 to 1.87.

Six samples were analysed from Garhmukteshar area. Probability plots of 3 samples yield, type I, II and type III grain size populations (Fig. 26d). Three samples show type I,1,type II, and remaining 2, type III grain size distribution. Inflection points between traction and saltation populations of type II are dispersed within the range of 1.5 to 2.5 Φ forming medium to fine sand grade, and between saltation and suspension populations within narrow range 3.0 to 3.5 Φ of very fine sand grade. Inflection points of type III grain size distribution between traction and saltation are in medium sand grade (1.5 Φ), and between saltation A and saltation B are also in medium sand grade (2.0 Φ). In type I grain size distribution, inflection point is in fine sand grade (3.0 Φ).

In each of the three types, proportion of sediment fractions of traction load varies from less than 1 to 3% by weight, in saltatioin load from 11 to 93% and suspension 5 to 86%.

Rajghat sediments:

The sand is coarse to very fine grained with mean size varying from (M_z) 2.0 to 4.0 Φ, very well sorted to moderately sorted ($б_I$) 0.35 to 0.74 Φ, strongly fine skewed to strongly coarse skewed (SK_1)+0.41 to -0.45, and platykurtic to very leptokurtic (K_G) 0.70 to 1.63.

Seven samples analysed from Rajghat area also exhibit three types of grain size distribution. Out of 7, 3 samples yield type II grain size distribution; 2 samples, type III, and remaining 2 samples, type I (Fig.27a). The particle diameter corresponding to the inflection points between traction and saltation population (in the case of type III between traction and saltation A) of 4 samples are dispersed in narrow range 1.35 to 1.5 Φ, exceptionally 1 sample corresponding to 3.0Φ. The truncation points between saltation and suspension (in the case of type III, between saltation B and suspension) are dispersed within the range of 3 to 3.5 Φ.

The proportion of saltation population, which constitutes the bulk of the load, varies from 6.8 to 98% by weight,

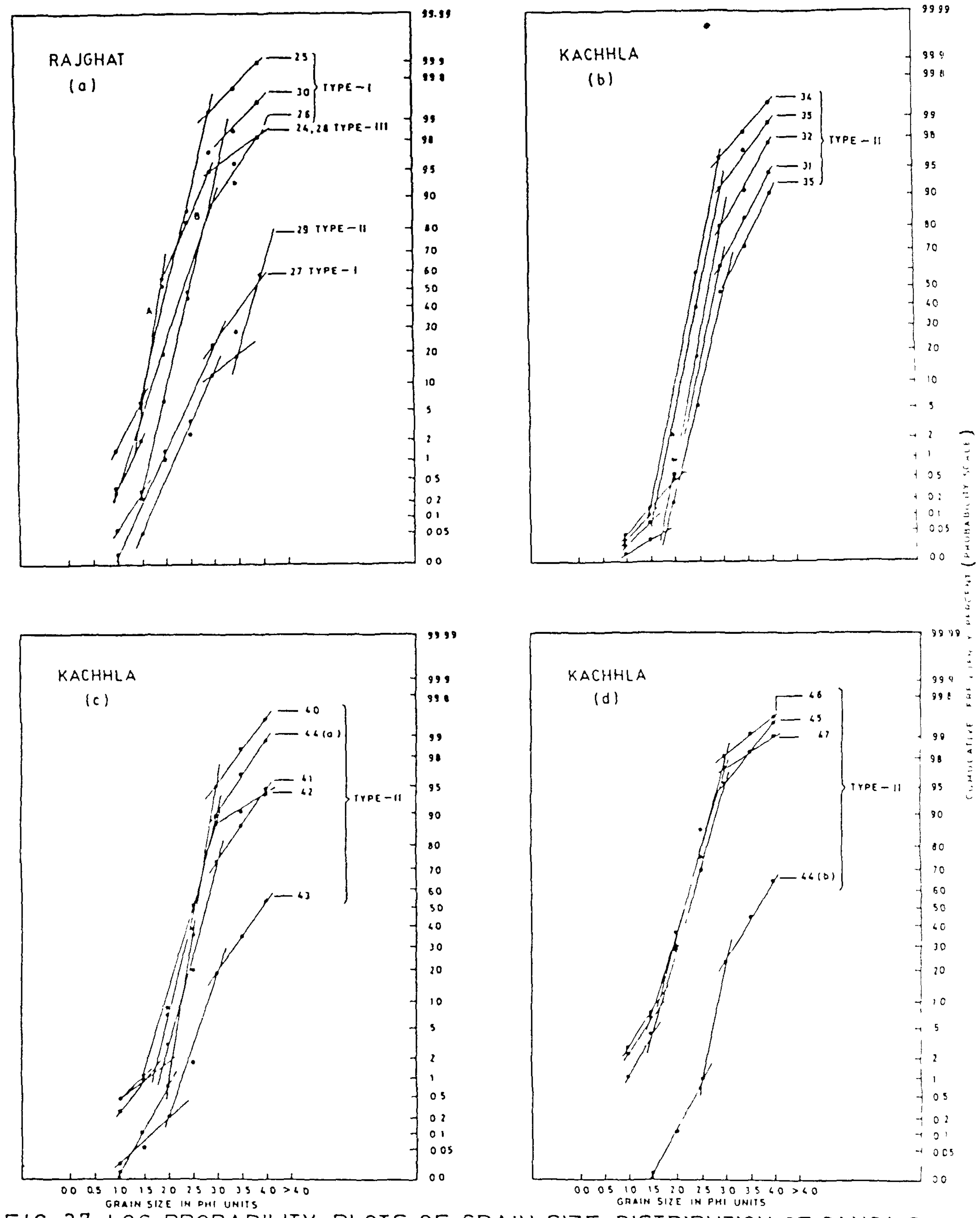


FIG. 27 LOG PROBABILITY PLOTS OF GRAIN SIZE DISTRIBUTION OF GANGA SAND

suspension load from 3.6 to 73%, and traction occurs in small amount from less than 1 to 12.2%.

Kachhla sediments:

The material is fine to very fine grained sand varying from (M_z) 2.1 to 3.71 Φ, very well sorted to moderately well sorted (σ_I) 0.28 to 0.61 Φ, strongly fine skewed to coarse skewed (SK_I) + 0.49 to -0.13, and very platykurtic to very leptokurtic (K_G) 0.67 to 1.84.

Kachhla sediments show only type II grain size distribution in all the 14 samples analysed (Fig. 27a, b & c). Particle diameters corresponding to inflection points between traction and saltation populations are dispersed within broad range 1.5 to 2.5 Φ. On the other hand the inflection points between saltation and suspension are dispersed within narrow range 3.0 to 3.13 Φ.

The proportion of sediment fraction in traction load is in small quantity varying from less than 1 to 7.5%. The bulk of the load is transported due to saltation process varying from 20 to 96%, and suspension load varies broadly from 5 to 79%.

Interpretation:

The resulting deposits are the mixture of three or less than three log normal populations produced mainly by three modes of transport, namely traction, saltation, and suspension. Varying shapes of grain size probability plots represent intermixing of these probability plots yielding sediments of variable particle size. As described by Moss (1962), and Visher (1969) the position of truncation

of probability plots, and sorting and mean size of individual sediment populations as well as those of the bulk sample help in understanding the nature of depositional processes.

By and large, the proportion of traction load is small varying in size from -1 to + 1.5 Φ, and show wide distribution of corresponding points (-1 to 1.5 Φ), may imply the variation in the intensity of depositing currents. This indicates that only that material was transported from the source area to which the current was capable to transport at that time.

The fine truncation points of traction populations are under the limit of 2Φ, which is attributed as the junction between Stokes and Impact or saltation and rolling populations (Fuller, 1961). Visher (1969) considered this size as the critical size where intertial forces cause rolling or sliding of particles rather than saltation. The traction process transporting nearly 15% or more load, having (-1.0Φ) and/or bigger particle size, may suggest the high intensity streams, possibly due to periodic rains, debris containing coarse fragments was rapidly transported onto depositional site.

Sorting is believed to reflect rate of deposition, and the strength and variation in the energy of the depositing current. Poor sorting indicates variable current velocities and turbulance during deposition while good sorting indicates smooth and stable currents. Most of the traction population samples show poor and fair sorting suggesting variable current velocities and turbulance during deposition. This is also indicated by appreciable variation in the truncation points between the traction population and saltation population.

The saltation population is a product of the moving grain layer or traction carpet of saltating grains. The amount of the saltation population depends upon the stability of the moving bed layer and the rate of deposition. The bulk of the load is transported under the saltation process. The saltation process also includes medium to coarse sand (less than 2Φ size) in the distribution, which indicates deposition by a system of turbulent 'continuous current'(Visher,1969).Saltation load commonly exhibits steeper probability plots(upto 80°)and inflection points are distributed within a narrow size range of 3.0 to 3.5Φ(most of the inflection points range in between 3.0 to 3.25Φ), may suggest that during the process of deposition the combined hydraulic factors (discharge, density, depth and velocity) attending the depositing current system plus bed roughness were more or less alike (Moss, 1963, Visher, 1969). As suggested by Visher (1969) good sorting of the saltation population appears to reflect reworking of sediments. The higher the velocity of the currents and the slower the rate of sedimentation, the better is sorting of this population. By implication, good to excellent sorting of saltation population indicates reworking of sediments.

The population transported under suspension process is highly variable. It varies from about 1% to 86% (of the total distribution) and by and large varies in size from very fine sand to silt with clay. Higher percetage of suspension population reflects high concentration (abundance) of suspended sediment in the depositing medium, and rapid rate of sedimentation. The suspension load was settled during the last phase of deposition when the velocity and vertical turbulance (buoyancy) of flow was sufficiently reduced. The upper size of suspension population is 3.0Φ, nearer to the upper size limit (0.1 mm or coarser) as described by Moss (1963). The break between saltation and suspension populations occurs between 3.0 and 3.3Φ, within the range (between 2.5 and 3.5Φ) described by Friedman and Johnson (1982, p.71).

Tractionn load, comprising of very fine granule to fine sand, occurs in minor (less than 1%) to small (15%) proportion. Saltation load, with few exceptions, forms the bulk of the load and suspension load, comprising of very fine sand, and silt with clay which occurs in subordinate amount.

It may be concluded that the saltation population was highly developed, showing good to excellent sorting, suggesting reworking of sediments, slow rate of sedimentation as the moving bed layer f saltating grains was stable. The process depositing saltation population was most effective during deposition of all the three types of populations. On the other hand the processes that deposited traction and suspension populations were more effective in type II distribution as indicated by higher percentage and better sorting of these populations.

The samples analysed from different areas show gradual and significant change in grain size distribution in down current direction. The distribution of sediments with respect to their median diameter shows that the largest grain size occurs along the main axis of flow where the highest velocities prevailed. There is a systematic variation in grain size along the profile of the river.

Roundness of grains:

Roundness is defined as the degree of curvature of a particle or the degree to which a particle is without sharp corners and projections. Roundness of a particle is a function of distance of transport, transporting agency, and environment of deposition. It is the physical property of a particle which depends upon the sharpness of the edges and corners.

Nine samples were analysed from Hardwar . The modal class lies in the 'subangular class' and contain 32 to 85 percent of the total grains. Six samples exhibit subangular, 2 angular and remaining 1 subrounded grains. The arithmatic mean roundness varies from 0.249 to 0.364. On an ave rage the sediments deposited at Hardwar are subangular, even though few subrounded and rounded grains were also deposited.

Coming down at Sherpur, roundness estimations were made from 6 samples and modal class lies in subrounded class which contains 36 to 46 percent by number of grains measured. The arithmatic mean roundness varies from 0.345 to 0.411. Out of 6 samples, 5 show subrounded grains, and the remaining 1 subangular.

Out of 6 samples analysed from Garhmukteshar area, 3 are subangular and the other 3 are subrounded. The subangular and subrounded detrital grains deposited are nearly in equal proportion. The arithmatic mean varies from 0.338 to 0.421.

Seven samples were analysed from Rajghat area and modal class lies in subrounded class, which contains 41 to 53 percent by number of total grains measured. The arithmatic mean roundness ranges from 0.370 to 0.402.

Further, coming down at Kachhla, 6 samples were analysed. In all the samples the grains measured are 'sub-rounded' and contains 51 to 54 percent by number of total grains. The arithmatic mean varies from 0.345 to 0.375.

Interpretation:

The 'roundness' of a particular mineral or rock fragment depends upon its hardness (softer grains rounding faster), and the cleavage or toughness (large grains with good cleavage tend to fracture rather than round, brittle pebbles also tend to fracture readily whereas quartz pebbles will round). It is found that coarser grains are more rounded as they are transported along the surface and collided with each other with greater impact. However, the finer grains are less rounded as they were transported in suspension.

In the study of roundness an abnormal relation between roundness and mineral hardness is important. This factor indicates whether the deposited grains are fresh or recycled. The well rounded tourmaline grains clearly indicates that they are recycled grains transported from the pre-existing sedimentary rocks. The sediments deposited upstream in the proximal area which have been transported only a little distance, are subangular, however, in the down current direction the roundness increases with the increase of distance of transport.

Sphericity:

Sphericity describes how closely a grain resembles a sphere, indeed it has been defined in a variety of ways. An easily understood definition involves the volume of the particle (Vp) and the volume of the smallest sphere (Vs) that will just enclose the particle. Shericity is thus defined equal to $\sqrt[3]{(Vp/Vs)}$ (Wadell, 1935). Sphericity reveals better behaviour of a particle during transport having maximum projection sphericity, $\sqrt[3]{(S^2/LI)}$, (Sneed and Folk, 1958).

In principle, a river is a very crude and insufficient shaper - presumably because of wide fluctuation in velocity (Dobkins and Folk, 1970). Further it is a complex function of lithology, pebble size and transport distance (Sneed and Folk, 1958). The sphericity values range from 0.4 to 0.9 (Table V) and are described as low (<0.4), moderate (0.4-0.8) and high (>0.8). Most of the gravel clasts have the sphericity of about 0.6-0.7.

Sphericity is a quantitative parameter measuring the departure of a body from equidimensionality. This quantity is a better measure of a particle behavior in a fluid medium. The equidimensional grains are not marked with preferred orientation, however, those which are flat discs assume pronounced imbrication. The quartzite clasts have high sphericity and increases with transport. However, weak clasts have lower sphericity and decreases with transport. For larger clast size, the sphericity is lower, while is higher for smaller clasts.

CHAPTER IV

MINERAL COMPOSITION

GENERAL REMARKS:

The mineral composition of Ganga sand has not been studied in detail. The present study is an attempt in this direction.

Methods of study:

Thirty two mounted slides of sand and 15 mounted slides of heavy minerals were examined. To study the mineral composition, small quantity of sand was directly mounted on glass slide with Canada balsam and examined under petrological mircroscope. 250 to 300 grains were counted from each slide. The mineral composition of the sand is shown in the table (VI).

Fuchtbaür (1974, p.36) described that heavy mineral species may vary in relative abundance with respect to grain size. It is believed that the size fraction finer than modal class records maximum concentration of heavy minerals (Rittenhouse, 1943). Therefore the class finer than the modal class was selected for heavy mineral analysis in the present study. The fraction of aforesaid class was treated in dilute HCl and heated for 15 to 20 minutes to remove iron coating. The samples were then washed with water to remove all the available acid and mud particles/fraction, if any, and dried

Table VI. Mineral composition of Ganga sand.

Sample No.	Modal composition (percent by number)																				
	Quartz	Mica		Chlorite	Amphibole		Garnet	Zircon	Tour-maline	Epidote	Rutile	Kyanite	Feldspar		Spinel	Anatase	Titanite	Silli-manite	Apatite	Rock fragments	Zoisite	Opaques
		Muscovite	Biotite		Actinolite /Termotite	Hornblende							Plg.	Orth.								
					Hardwar																	
4	46	9	3	5	3	2	2	4.1	3	4.1	1	-	2	3	-	3	-	2	-	2	-	3
5	41	18	6	-	2.2	1.3	4	7	4.1	2.1	-	-	2.2	4	-	-	-	-	-	7	-	1.1
6	40	16	5	6	2.3	1.2	5.3	5.2	4.2	-	-	-	-	-	-	-	-	-	1.2	6.1	-	2.5
7	46	13	6	4	3	-	9.2	4.1	3.1	2.2	-	-	-	2.3	-	-	1.1	-	-	5	-	-
8	35	15	5	6	4	2.2	4	4	2.1	3.2	2.3	-	3	5	-	-	2.1	-	-	5	-	2.1
9	34	12	4	3	1	-	7	5	4	1.2	3	1.2	2.3	7	2.1	1.2	-	-	1.1	7	-	2
10	33	13	7	5	6	-	4	4	2.3	2.3	3	2.1	2	6	-	1	-	-	-	6	-	2
11	34	11	5	5	5	-	6	4.9	3.7	1.6	3	1.3	-	6	-	-	-	-	-	8	-	3.5
12	38	13	3	5	3	6	8	4	1.2	-	2.3	2	3	5	-	1.2	1.2	-	-	7	-	2.2
					Sharpur																	
13	34	14	4	4	3	3	4	4	4	1.2	3	2.3	3.1	5	-	1.2	-	-	1.2	9	-	3
14	35	15	4	8	7	2.4	4	4	4	4	1.3	2.4	-	2.4	-	-	-	1.3	-	-	-	3.2
15	30	17	5	5	5	1	5	5	4	5	-	-	3	5	-	-	-	-	-	6	2	2
16a	40	16	5	3	4	3	7	3	4	3	-	-	-	1.3	-	2.3	-	-	-	2.1	2.3	2
					Garhmukteshar																	
17	41	8	5	6	4	-	11	3	3	-	2.1	2.4	-	-	2.3	-	-	-	-	5	-	2.2
18	34	9	6	4	1.3	1	5	3	5	4	2.2	1.3	5	5	2.2	-	-	-	-	5	-	3
19	46	11	4	3.2	4	-	1.3	5	3.2	-	5	-	2.3	8	-	-	-	-	-	8	-	4
20	51	12	5	5	2.2	-	3.1	3	3	-	1.4	2.1	2.1	2.1	-	-	-	-	-	6	-	2
21	46	13	6	5	3	-	4.3	4.3	3.5	-	2.5	-	-	-	-	-	-	2.2	-	4	-	3.2
22	49	16	5.5	4.8	6.2	1.5	-	2.4	1.6	4	1.4	-	7	2.6	-	-	-	-	-	11.3	-	4.7
23	43	11	3	5	3	1.4	8	3.1	3.1	-	2.3	3.1	-	3.3	2.3	-	-	2.2	-	5	-	2.2
24	34	14	5	6	7	-	4.2	2.3	3.2	2.3	-	-	4.2	6	2.4	-	-	-	-	5.2	-	3.2
					Rajghat																	
25	32	13	5	4.6	-	-	5.4	10	4	-	2.3	1.4	-	-	5.1	-	-	-	-	6.2	-	5
26	41	11	5	5	4	1	6	3	3	1	3	-	2	4	4	-	-	-	-	6	-	4
27	30	9	8	8	4	-	4.3	4.3	5.4	6	-	-	1.2	3.2	5	3.3	1.3	-	-	7	-	5
28	52	8	4	4	2.1	-	-	6	3	-	-	2.1	2.1	4	3.3	-	4	2.2	-	5	-	3.2
29	42	11	5	1.2	3	1.3	12	3	3	-	-	-	2.1	3.2	4.1	-	-	-	-	5	-	4.2
30	33	14	8	8	4	2.3	4	6	5	-	-	-	2.3	3.4	6	-	2	-	-	6	-	6
					Kachhla																	
36	60	2	1.5	5	0.6	0.3	12.1	1.2	1.8	-	-	1.8	0.3	1.2	2.7	0.3	0.6	0.6	-	-	3	1.5
37	65	2.5	2.3	6	-	-	2.3	1.1	5.3	1.2	0.6	5.4	-	-	1.2	-	-	2.4	-	0.6	3	4
38a	61	3.2	1.2	11	1.8	2.4	9	3	1.2	-	0.2	2	-	0.2	1.3	0.2	0.2	0.7	0.2	-	2.6	6
39	64	3.2	4	7	1.3	-	1.8	0.2	0.2	2	1	1.6	-	0.5	0.5	-	-	-	-	-	8	6
49	53	3.3	5.6	9.6	0.5	-	4.3	-	[illegible]	0.6	-	5.9	-	-	0.6	1.7	-	1.1	-	-	1.7	5

in oven. Heavy mineral separation was carried out using bromoform (sp. gr. 2.86) as heavy liquid and a centrifuge machine following the procedure outlined by Muller (1967).

After drying the heavy mineral residue, a pinch of grains was mounted on a glass slide using Canada balsam and examined under petrological microscope. Individual heavy mineral species were distinguished on the basis of their petrographic characters. To determine the frequency of heavy species, 250 to 450 grains were counted form each slide. Table VII records the heavy species and figure (28) illustrates overall frequency distribution of heavy mineral species at Hardwar, Rajghat and Kachhla. Figure 29 shows the distribution of heavy mineral species in each sample at aforesaid areas.

Lighter Minerals:

Quartz : Quartz is the most abundant mineral ranging from 30 to 65% in the Ganga sands. Both monocrystalline and polycrystalline varieties have been identified. Generally the grains are subangular to subrounded, but angular and rounded grains are not uncommon. The angular grains are marked with fractures while the subrounded and rounded grains are marked with smooth surface. Quartz grains are colourless in ordinary light and owe brilliant interference colours in the form

Table VII. Heavy Mineral Composition of Ganga sand

Sample No	Garnet	Muscovite	Biotite	Titanite	Epidote	Chlorite	Hornblende	Kyanite	Staurolite	Rutile	Hypersthene	Tremolite/ Actinolite	Tourmaline	Zircon	Zoisite	Apatite	Spinel	Anatase	Sillimanite	Opaques
					Hardwar															
6.	43 36	15 92	0 88	2 65		1 76	2 65	0 88	-	0 88	0 88	-	12.38	D.88	-	-	2.65	0.88	0.88	12.38
7.	13 17	0.77	-	11 62	1 55	5 42	6 20	1.55	1 55	0 77	-	-	41 08	2.32	-	0.77	8.52	0.77	2.32	1.55
8.	12 5	4 16	-	11 11	2 77	5 55	5 55	4.16	4 16	2 77	2 77	4 16	26 38	5.55	-	1.38	8.33	-	4.16	2.77
11.	33 33	1.51	-	7 57	-	9 09	1.51	4.54	-	1 51	-	-	13 63	4.54	-	-	7.57	-	3.03	12.12
12.	14.28	7.57	1.68	5.04	2.52	9.24	5.04	9.24	4 20	-	1.68	0.84	12.60	5.88	2.52	0.84	4.20	1.68	5.04	5.88
					Rajghat															
23.	37 07	2.24	0 56	2.24	0.56	0.56	2.24	2.24	1.68	0 56	1.12	-	29 77	1.68	0.56	-	2.80	2.80	1.12	2.80
24.	32 67	1.57	0.39	2.36	1.18	0.39	0.39	-	1.57	-	-	-	40 55	8 66	-	1.18	3.54	0.39	1.18	3.93
25.	28 99	1.77	0 59	1 18	-	1 77	1 77	0.59	1.77	-	0 59	-	44.97	8.28	-	-	1.77	1.18	1.18	3.55
27.	6.94	2.77	1 38	15 27	-	2 77	4.16	2.77	-	-	-	-	34.72	4.18	2.77	-	6.94	2.77	12.5	2.77
28.	21 25	3 14	-	3.14	1.57	0 78	1.57	-	1 57	0 78	1 57	1 57	38.58	3.14	1.57	1.57	2.36	3.14	2.36	11.81
					Kachhla															
36.	23.22	5.68	0 47	0.94	2 84	1 42	0 47	2 84	2 36	0 49	0 49	0 49	42.65	5.68	2.36	-	1.42	-	3.31	1.42
37.	26 49	0 85	-	0 85	3 54	1 28	4 2	2 99	0 85	-	1 28	1 70	30.34	14.10	0.58	0.85	0.85	0.85	1.28	6.41
39.	3 41	5 98	4 27	4 27	7 69	11 11	2 56	2 56	1 70		0 85	0 85	30.76	3 41	-	0.85	12.82	0.85	3.41	2.56
48.	22 34	0 75	0 37	1 89	2 27	1 13	2 27	2 27	1 89	-	1 51	1 13	45 45	3 03	0.75	0.37	1.5	1.89	2.27	5.68
59.	16 17	6 61	0 73	2 20	2 20	8 08	2 94	4 41	2 20		2.20	2794	32.35	8 08	0.73	-	0.73	3.67	-	3 67

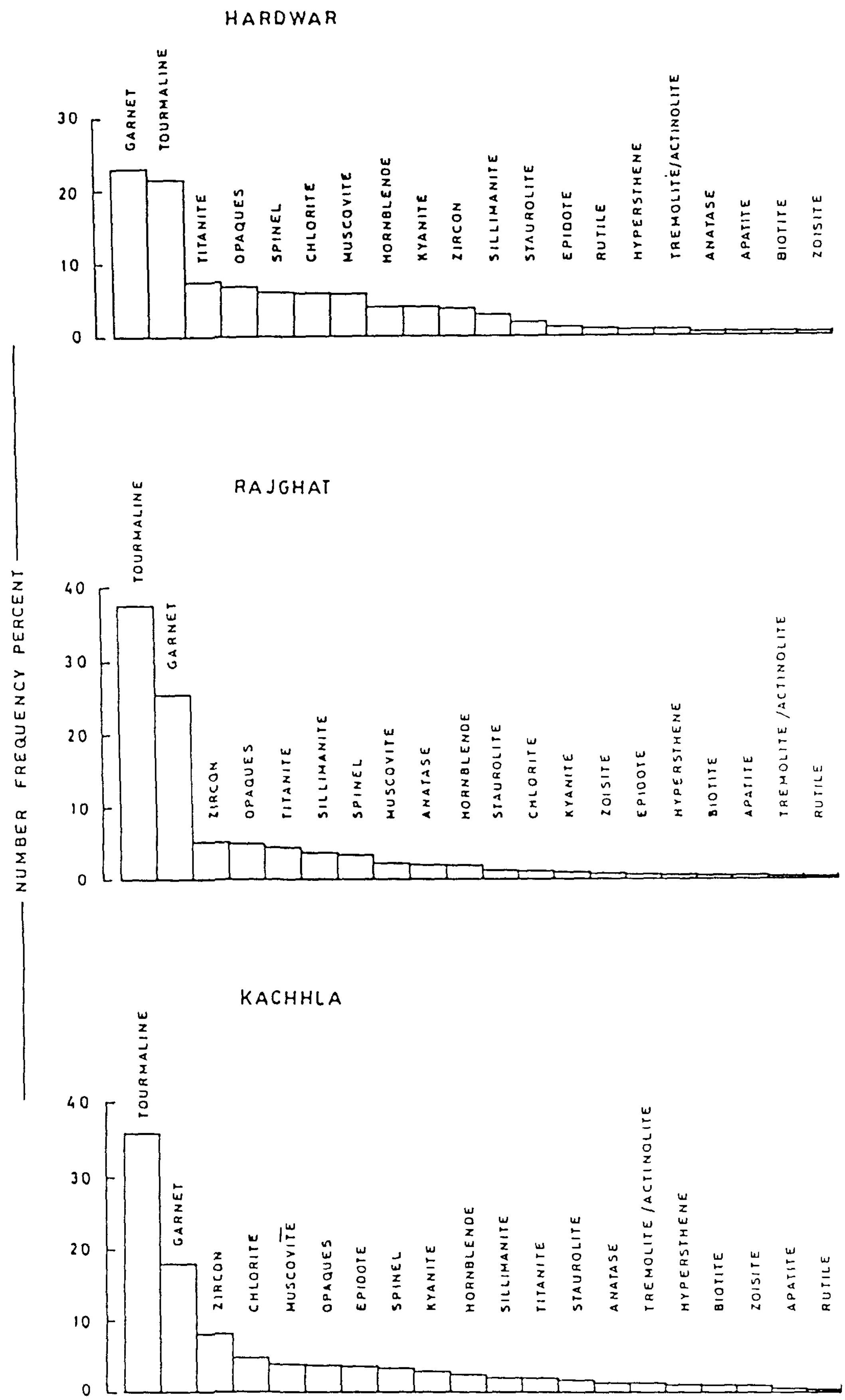


FIG. 28 BAR DIAGRAMS SHOWING AVERAGE FREQUENCY DISTRIBUTION OF VARIOUS HEAVY MINERALS AT HARDWAR, RAJGHAT AND KACHHLA

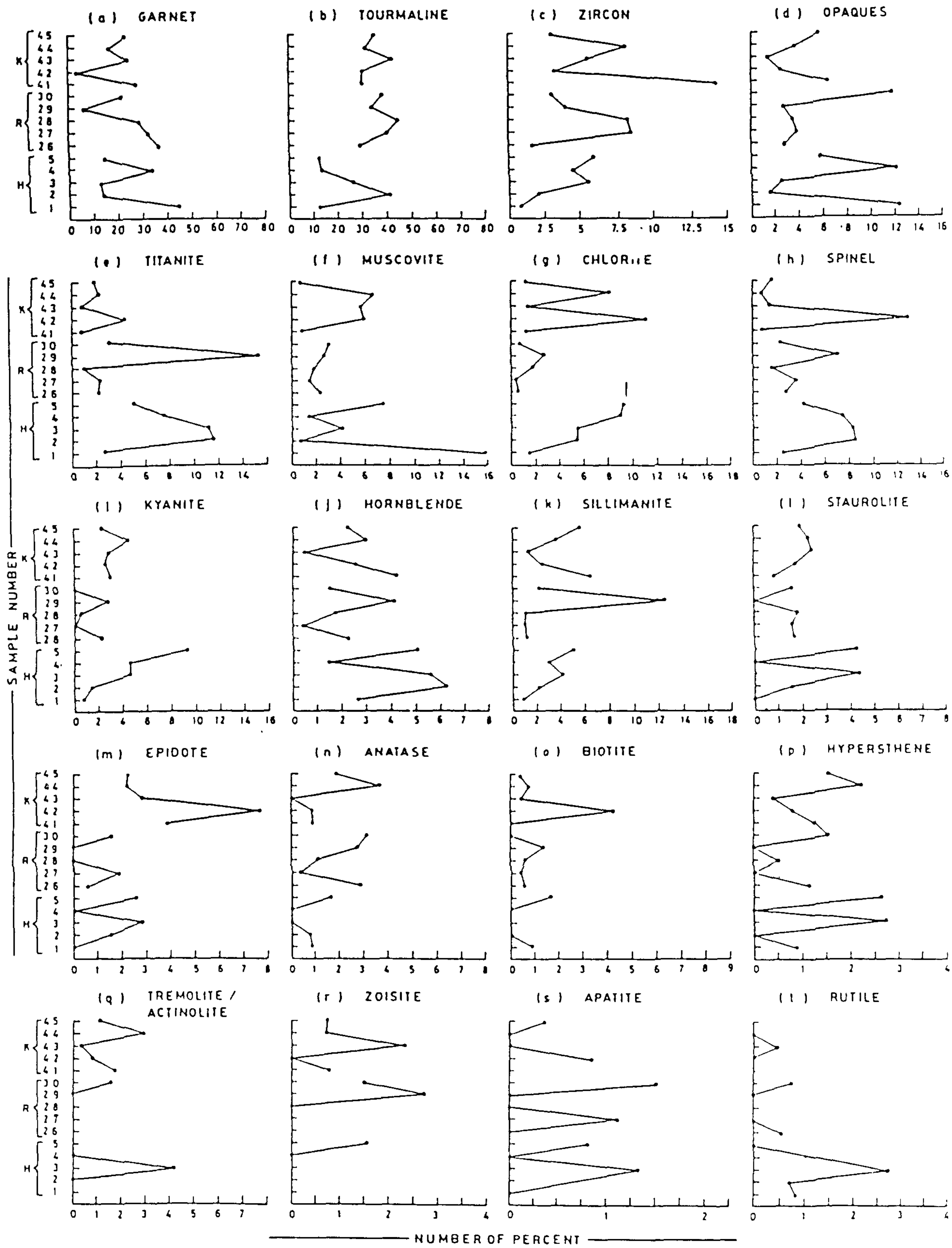


FIG.29 SHOWING HEAVY MINERAL DISTRIBUTION AT (H) HARDWAR, (R) RAJGHAT AND (K) KACHHLA.

of rings in cross nicols. Most of the grains exhibit straight extinction while others wavy extinction. Various inclusions of zircon, tourmaline, rutile needles and opaques are present. Some of the grains are filled either with liquid or gas.

Feldspar: Two types of feldspar have been identified.

Orthoclase Feldspar: The percentage of orthoclase ranges from 1.3 to 9% by number. The grains are colourless and show low relief and two sets of cleavage and are angular to sub-rounded. Some grains are slightly weathered. The grains show straight extinction and low order interference colours.

Plagioclase Feldspar: The percentage of plagioclase ranges from 0.6 to 7%. Most of the grains are colourless and show grey colour in cross nicols. The grains are prismatic in outline, however, angular to subrounded grains are also present. The plagioclase shows different twinning laws.

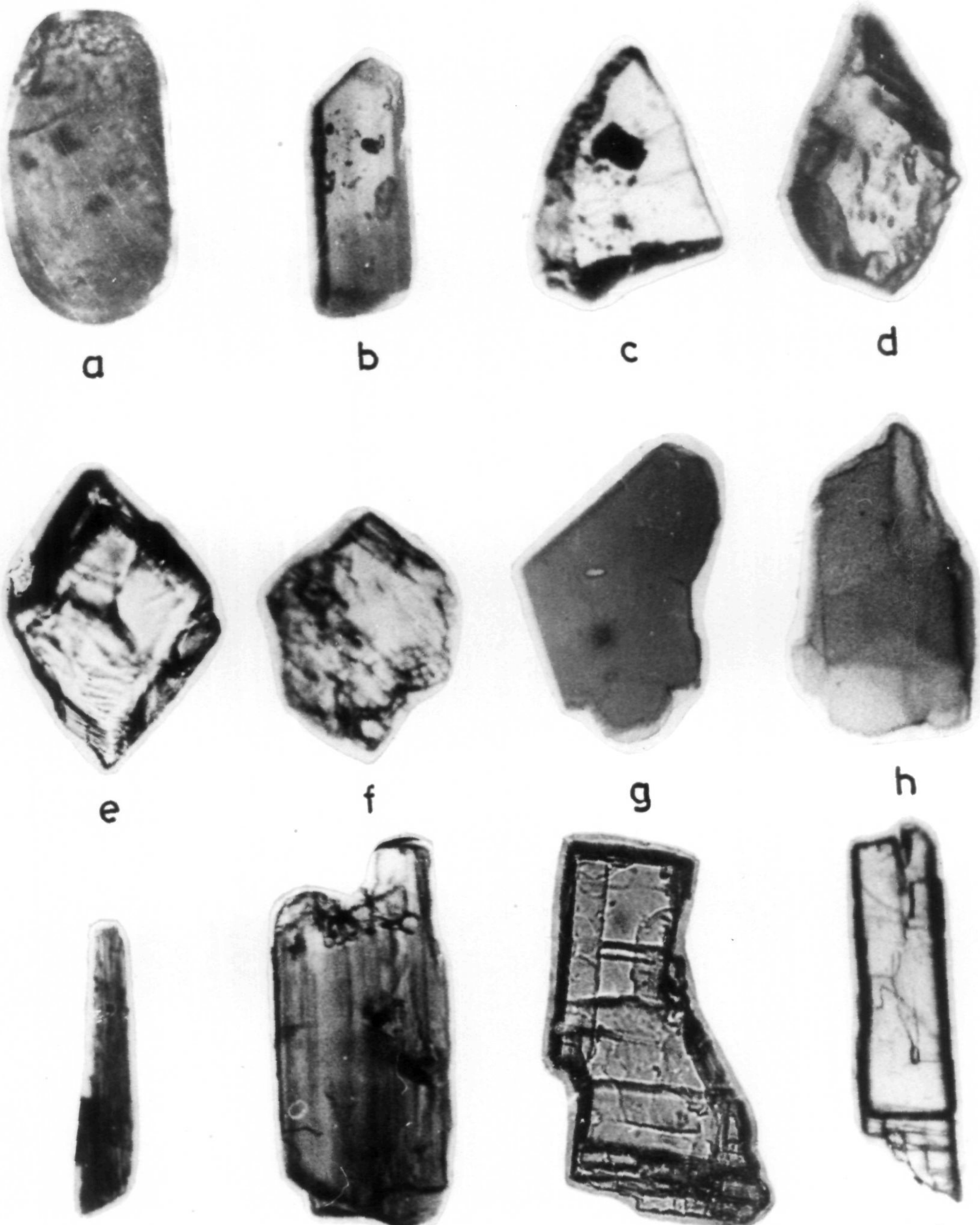
Rock Fragments: Rock fragments range from 2 to 11.3% by number. Most common rock fragments are of various schists, gneisses, and quartzites. However, some fragments of phyllite have also been recorded.

Heavy Minerals:

Tourmaline: Tourmaline is the most commonly occuring and by far the most abundant heavy species in the Ganga sands and constitutes 12.3 to 41% (average 21.2%) at Hardwar, 29.7 to 44.9% (average 37.7) at Rajghat, and 30.3 to 45.4% (average 36.3) at Kachhla by number. Various shades of colour exhibited by this mineral are brown, green, greenish brown and blue. Green variety is dominant. Most of the grains are prismatic, however, subrounded to well rounded grains are also present (Plate Ia). Angular grains are evidence of little abrasion. Tourmaline is strongly pleochroic, marked with striations and shows parallel extinction.

Garnet: Garnet ranks second in order of abundance among the heavy species. The amount of garnet, by number, varies from 43.3 to 12.5% (average 23.3%) at Hardwar, 37 to 6.9 (average 25.3%) at Rajghat and 26.4 to 3.4%(average 18.3) at Kachhla. On the basis of colour four varieties of garnet have been distinguished. The colourless variety is most abundant followed by light pink, however, brown and red varieties are rather rare. Grains are roughly equidimensional, marked with fractures on the surface, those broken are sharply chipped (Plate Ic & d). Grains often show pitted surface and are subangular to subrounded.

PLATE -I



EXPLANATION OF THE PLATE

PLATE - I

a & b.	Well rounded, prismatic tourmaline showing inclusions of opagues.
c & d.	Garnet-grains showing fractures and unidentified inclusions and pitted surface.
e & f.	Zircon-grains showing fractures. **e** shows well developed crystal faces in the form of pyramid.
g.	Titanite-angular to subangular in out line, marked with fractures.
h.	Spinel-marked with conchoidal fracture and slightly worn octahedra.
i.	Sillimanite-fibres in nature, irregularly terminated and striations are parallel to length.
j.	Hornblende-elongated in form showing dark colour in the middle and light towards the boundaries.
k & l.	Kyanite-marked with rectangular outline, elongated and two sets of cleavage.

Zircon: Zircon ranges between 5.8 to 0.8% by number (average 3.83%) at Hardwar, 8.2 to 1.6% (average 5.1%) at Rajghat and 14.1 to 3% (average 6.8%) at Kachhla. Based on colour, three varieties of zircon are distinguishable, namely, colourless, pink and light yellow. Colourless variety is most common. Most grains show abraded margins and are angular to subrounded. Some grains show well developed crystal faces in the form of pyramids (Plate Ie). The grains show high relief and are marked with fractures. Inclusions of opaque minerals are present.

Opaques: The amount of opaque minerals varies from 12.3 to 1.5% (average 6.9%), 11.8 to 2.7 (average 4.9%), and 6.4 to 1.4% by number at Hardwar, Rajghat and Kachhla respectively. The grains are angular to subrounded. Among the opagues, three varieties have been identified on the basis of colour in reflected light.

i.	Hematite	-	reddish brown
ii.	Magnetite	-	silver black
iii.	Limonite	-	yellowish brown

Titanite: Titanite ranges from 11.6 to 2.6% (average 7.5%), 15.2 to 1.1% (average 4.8%) and 4.2 to 0.8% (average 2.0%) by number at Hardwar, Rajghat and Kachhla respectively. Generally the grains are irregular in shape and show brown, brownish yellow colour, however, yellowish green titanite grains are not uncommon. The grains are marked with absence of extinction and show the change in the intensity of colours in cross nicols.

Spinel: Spinel varies from 8.5 to 2.6% (average 6.2%) by number at Hardwar, 6.9 to 1.7% (average 3.4%) at Rajghat and 12.8 to 0.7% (average 3.4%) at Kachhla. Based on colour, red, reddish yellow, and light green varieties of spinel have been identified. The grains of spinel are rounded to slightly worn octahedra and are isotropic in nature. The conchoidal fracture is very characteristic. Inclusions of tourmaline and zircon were observed.

Muscovite: Muscovite content varies from 15.9 to 0.7% (average 5.9%) by number, 3.4 to 1.5% (average 2.3%) and 6.6 to 0.7 (average 3.9%) at Hardwar, Rajghat and Kachhla respectively. The grains are colourless and occur in the form of thin flakes. The flakes are angular to subangular but rounded flakes are also present.

Sillimanite: Sillimanite varies from 5.0 to 0.8% (average 3.0%) by number at Hardwar, 12.5 to 1.1% (average 3.6%) at Rajghat. This mineral is not observed in all the samples examined from Kachhla. Occurrence of sillimanite at Kachhla varies from 3.4 to 1.2% (average 2.0%) by number. On the basis of colour two varieties of sillimanite colourless and green have been identified. Colourless variety is dominant. Sillimanite grains occur as slender prism or fibres with fractured or irregular terminations (Plate Ii). The grains show tendency of longitudinal splitting and have striations parallel to length. Generally the grains are subangular to subrounded.

Chlorite: Chlorite content varies from 9.2 to 1.7% (average 6.2%), 2.7 to 0.3% (average 1.2%) and 11.1 to 1.1% (average 4.6%) by number at Hardwar, Rajghat and Kachhla respectively. Chlorite is not a single mineral but is a group of unseparated minerals. It occurs as flat, rounded and irregular flaks. The grains are pale green to dark green in colour with black spots and show blue polarization colour.

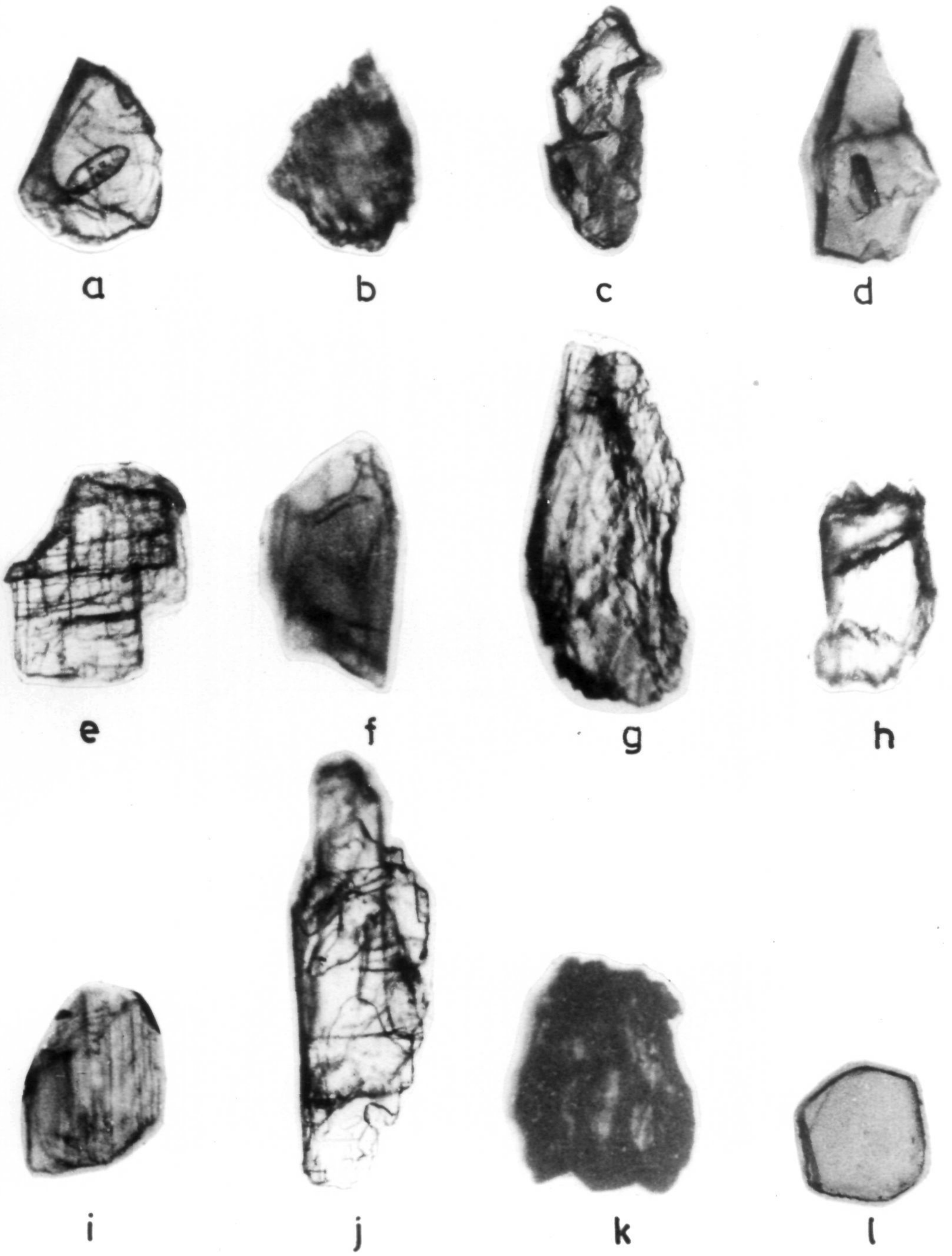
Hornblende: Occurrence of hornblende varies from 6.2 to 1.2% (average 4.2) by number at Hardwar, 4.1 to 0.3% (average 2.0%) at Rajghat and 4.2 to 0.4% (average 2.4%) at Kachhla. Hornblende shows characteristic green colour. Usually the grains are elongated and irregularly terminated. The colour is unevenly distributed in the grains, being darkest in the middle and becoming gradually light towards the boundaries (Plate Ij).

Kyanite: Kyanite varies from 9.2 to 0.8% (average 4.0%) by number at Hardwar. It does not occur in all the samples examined from Rajghat. It varies from 2.7 to 0.5% (average 1.1%) by number at Rajghat and 4.4 to 2.5% (average 3.0%) at Kachhla. Only colourless variety of Kyanite is identified. The grains are subangular to subrounded and elongated marked with rectangular outlines (Plate Ik & l).

Epidote : Epidote is not observed in all the samples examined from Hardwar and Rajghat. The amount of epidote varies from 2.7 to 1.5% (average 1.3%) by number at Hardwar, 1.5 to 0.5 (average 0.6%) at Rajghat and 7.6 to 2.2% (average 3.7 at Kachhla. Based on colour, pale greenish yellow, lemon yellow and dark green varieties of epidote have been identified. The grains are irregular, subangular to subrounded. Inclusions of elongate pyramidal zircon are present (Plate IIa).

Staurolite: Staurolite is not identified in all the samples examined from Hardwar and Rajghat. The content of staurolite varies from 4.1 to 1.5% (average 1.9%) by number at Hardwar, 1.7 to 1.5% (average 1.3%) at Rajghat and 2.3 to 0.8%(average 1.8) at Kachhla. Based on colour, straw yellow and brownish yellow varieties of staurolite have been identified. Straw yellow variety is dominant. The grains are irregular, sub-angular to subrounded with hackly to subconchoidal fractures. Unidentified inclusions are present (Plate IIc & d).

PLATE-II



EXPLANATION OF THE PLATE

PLATE - II

a & b Epidote - **a** showing inclusion of pyramidal zircon, **b** showing irregular outline and cloudy appearance.

c & d Staurolite- showing irregular outline, subconchoidal fracture and unidentified inclusions.

e Anatse-showing 'geometric patterning'.

f Hypersthene-showing schiller structure.

g & h Tremolite/Actinolite - showing fibres and irregular outline.

i & j Zoisite - prismatic and subrounded in form (i). Clinozoisite (j) is elongated and inclusion of well rounded tourmaline is present.

k Rutile-angular to subangular marked with dark border.

l Apatite-subrounded grain showing hexagonal form.

Anatase: All the samples examined from Hardwar and Kachhla do not contain this mineral. It varies from 1.6 to 0.7% (average 0.6) by number at Hardwar, 3.1 to 0.3% (average 2.0%) at Rajghat and 3.6 to 0.8% (average 1.4%) at Kachhla. The grains are rectangular, subhedral in form and show frequent development of zoning or 'geometric patterning'(Plate IIe).

Hypersthene: The content of this mineral varies from 2.7 to 0.8% (average 1.0%) by number at Hardwar, 1.5 to 0.5% (average 0.6%) at Rajghat and 2.2 to 0.4% (average 1.2%) at Kachhla. It is not examined in all the samples analysed from Hardwar and Rajghat. It shows greyish green and pale green colour. Usually it occurs as prismatic, subangular to subrounded. Hypersthene shows schiller structure.

Actinolite/Tremolite: Actinolite/tremolite occurs in minor amount in the samples examined from Hardwar and Rajghat. It is examined in 2 samples from Hardwar and only 1 sample from Rajghat. However, it is present in all the samples examined from Kachhla and varies from 2.9 to 0.4% (average 1.4%) by number. Actinolite is green in colour, whereas tremolite is colourless. Generally the grains are irregular (Plate IIh), elongated and prismatic. Actinolite grains are marked with fibres nature.

Zoisite: Zoisite does not occur in all the samples examined from Hardwar, Rajghat and Kachhla. At Hardwar, it is examined only in 1 sample. It varies from 2.7 to 0.5% (average 1.2%) by number at Rajghat and 2.3 to 0.7% (average 0.9%) at Kachhla. On the basis of colour yellowish brown, pale green, and colourless varieties of zoisite have been identified. It occurs as prismatic grains and shows straight extinction. Clinozoisite variety differs from zoisite in its oblique extinction (Plate IIj).

Biotite: It is not present in all the samples examined from Hardwar, Rajghat and Kachhla. At Hardwar, it occurs in 2 samples and varies from 1.6 to 0.8% (average 0.4%) by number. At Rajghat its amount varies from 1.3 to 0.3% (average 0.5) by number and at Kachhla from 4.2 to 0.3% (average 1.1%). Biotite occurs mostly in the form of flakes and shows borwn, greenish and yellowish colour.

Rutile: Rutile occurs in minor amount. At Hardwar, it varies from 2.7 to 0.7% (average 1.1%) by number. At Rajghat it is identified in 2 samples, however, at Kachhla it is identified in 1 sample. The grains are angular to subangular. Elongated prismatic forms occur with rounded pyramidal ends. Rutile grains show high relief, central part is characterised by blood red colour and border is dark (Plate II k).

Apatite: Least occurring mineral in Ganga sands is apatite. It is identified in 3 samples from Hardwar, 2 from Rajghat and 3 from Kachhla. The apatite grains are colourless hexagonal and slightly worn elongate prismatic terminated by pyramids. Most of the grains are rounded (Plate II1).

Interpretation:

Heavy minerals are of great value in studying provenance, transportation and weathering history of a sediment and in correlation. Shapes and roundness of the heavy minerals are sensitive indicators to the intensity of abrasion. Sedimentologists have defined certain assemblages of heavy minerals for deciphering the composition, location and tectonic history of provenance (Pettijohn et al., 1973, Fuchtbaur, 1974, Pettijohn, 1975, p. 628, Blatt et al., 1980). They are also useful in evaluating diagenetic history as well as the pre-erosional history (Lindholm, 1987, P. 208).

Presence of various heavy mineral species in the Ganga sands indicates that the sediments may have been derived from a variety of source rocks. The heavy mineral suite is dominated by tourmaline. Brown variety of tourmaline is derived from pegmatised injected metamorphic terrains, green from granitic rocks and blue from pegmatites (Krynine, 1946). However, well rounded tourmaline have been derived from sedimentary source indicating more than one cycle of transport. Colourless garnet may have been derived from schists, light pink garnet from acid igneous rocks e.g. granite and red garnet from igneous and metamorphic rocks, particularly crystalline gneisses and schists. Zircon and rutile may have been derived from sialic igneous and crystalline metamorphic rocks (Friedman and Johnson, 1982, p. 99). Muscovite may have been derived from low grade metamorphic rocks. (Folk, 1961, p.84). Epidote may have been derived from crystalline metamorphic rocks, originally rich in ferromagnesium minerals; hypersthene from intermediate, basic and ultrabasic igneous rocks.

It is apparent from the above study that the bulk of the heavies have been derived from a mixed assemblage of acid and basic igneous rocks and low to high grade metamorphic rocks. Well rounded tourmaline indicates its derivation from sedimentary source. The presence of large amount of tourmaline, garnet and zircon, suggests that the energy of depositional agency was higher.

CHAPTER V

FLOW PATTERN AND FLUVIAL MODEL

FLOW PATTERN

GENERAL REMARKS:

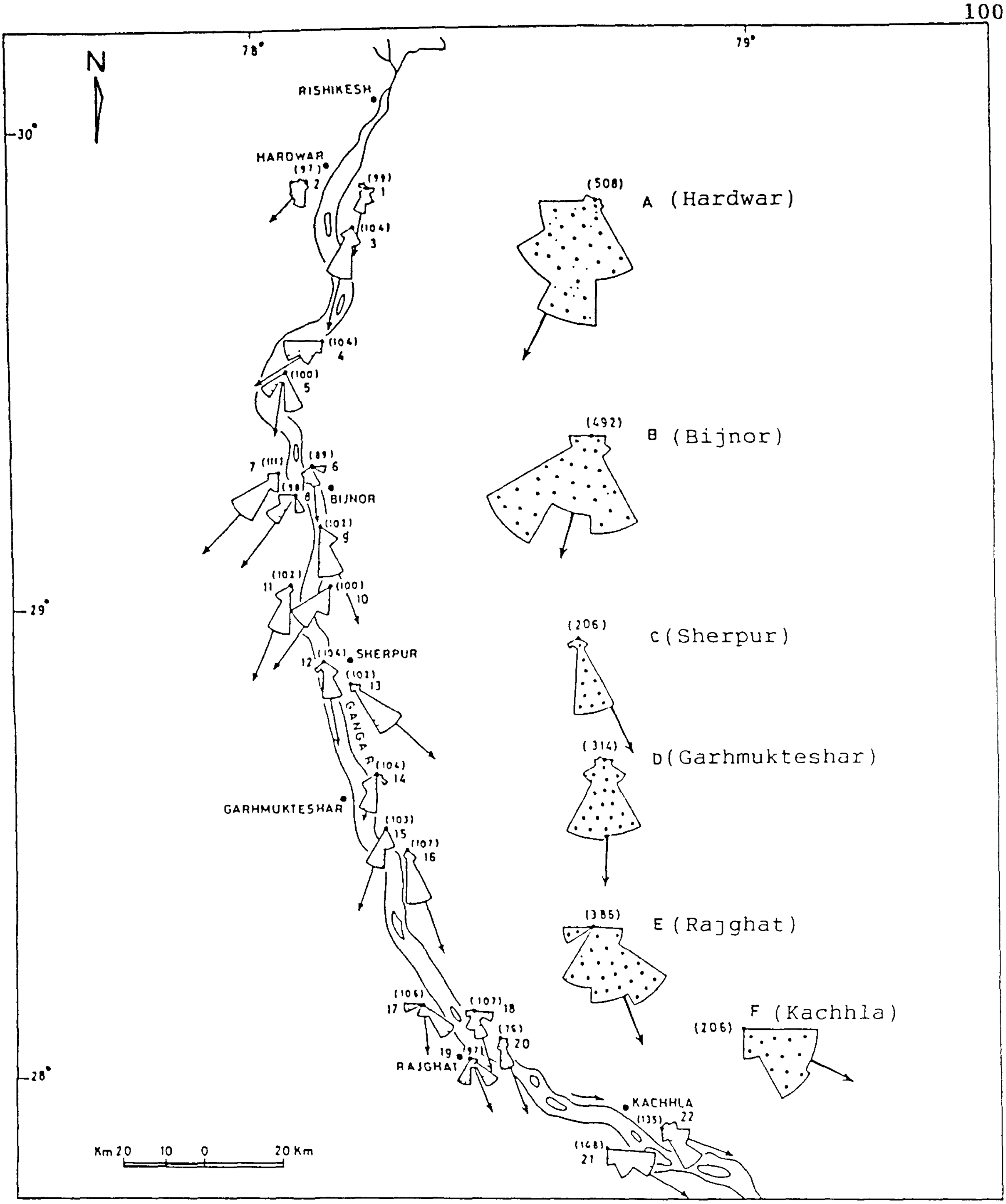
Paleocurrent studies have long been carried out in ancient sandstone bodies. Sorby (1859) was the first to systematically measure the cross-stratification, although, he apparently neither published a current rose nor plotted his measurements on a map. Brinkmann (1933) was, perhaps the first of the 'modern' workers to have a clear concept of objectives of paleocurrent research. A new interest was created after Potter and Olson (1954). They used the cross-stratification as a tool for determination of paleocurrent.

Since 1963, the study of dispersal patterns, and basin analysis with the help of primary sedimentary structures of modern environments is in progress. Good examples of such studies for alluvial sediments are those of Williams (1971). Picard and High (1973), Smith (1972) and Coleman (1969).

The present study aims at to record the variation in flow pattern with the help of directional primary sedimentary structures. The Ganga River, which is braided provide ample opportunity to show the typical flow pattern of the braided river model. Suitable sites were selected in the down current direction and measurements of primary sedimentary structures were made. The measurements were made twice in a year, I measurements were before the floods and the II after the floods as and when the bars were exposed. The measurements of two major types of cross-stratifications i.e. planar and trough were recorded. In case of planar cross-stratification, azimuths were directly measured with the help of clinometer compass, whereas for the trough cross-stratification, azimuth of the acute bisectrix of the curved surface was taken as the true azimuth of the foreset surface. A total 2112 measurements of the cross-stratification azimuths spread over 22 localities were made. The rose diagrams (Fig.30) show distribution of dip azimuth at locality level and at sector level. Thin arrow indicates vector mean at locality level and thick at sector level. The vector mean (θv) and vector magnitude (L%) for each locality and sector as a whole were calculated using vector summition method (Curry, 1956). The results are listed in the table (VIII).

Vector mean:

The vector mean is the most commonly used and accepted parameter dealing with the orientation data (Curry, 1956; Potter and Pettijohn, 1977, p. 425). Curry (1956) demonstrated that the vector mean provided a unique value of central tendency, irrespective of choice of origin of measurements.



100 % / 50 % / 0 % — ROSE DIAGRAM SHOWING THE FREQUENCY DISTRIBUTION OF CROSS STRATIFICATION AZIMUTHS IN 30° CLASS INTERVAL (IN PERCENT) NUMERALS WITHIN BRACKET REPRESENTS NUMBER OF MEASUREMENTS AND WITHOUT BRACKET INDICATE LOCALITY NUMBER.

100 % / 50 % / 0 % — THIN ARROW INDICATES VECTOR MEAN (IN PERCENT) AT LOCALITY LEVEL AND THICK ARROW AT SECTOR LEVEL LENGTH OF THE ARROW IS PROPORTIONAL TO VECTOR MAGNITUDE (L %).

ROSE DIAGRAM AT LOCALITY LEVEL

ROSE DIAGRAM AT SECTOR LEVEL

FIG. 30 MAP SHOWING VARIATIONS IN FLOW DIRECTION FROM GENERAL FLOW DIRECTION

Table VIII. Vector mean (Øv), Vector magnitude (L%), Standard deviation(σ_I), and Variance (S^2) of cross-stratification dip azimuths.

Sector	Locality number	Locality level n	Øv	L%	σ_I	S^2	Sector level n	Øv	L%	σ_I	S^2
A.	1.	99	188	67	52	2728	508	208	75	35	1209
	2.	97	223	79	36	1302					
	3.	104	193	95	17	309					
	4.	104	236	92	22	490					
	5.	102	190	88	23	797					
B.	6.	89	172	76	49	2433	492	194	78	36	134[illegible]
	7.	111	221	96	16	269					
	8.	98	217	85	33	1085					
	9.	102	156	97	14	195					
	10.	100	214	96	14	214					
	11.	102	200	95	16	274					
C.	12.	104	170	87	29	858	206	151	87	29	88[illegible]
	13.	102	134	96	14	212					
D.	14.	104	191	18	37	1385	314	182	83	34	1209
	15.	103	198	87	30	933					
	16.	107	159	94	20	437					
E.	17.	106	171	67	49	2470	386	159	88	40	1059
	18.	107	163	75	34	1175					
	19.	76	158	90	26	675					
	20.	97	158	85	31	1003					
F.	21.	148	117	85	32	1065	283	114	79	19	376
	22.	135	108	82	33	1139					

The vector mean values determined at sector-A for 5 localities range from 190° to 236°, that is within the range of 46° at locality level and at sector level is 206°. At sector-B, the vector mean was determined for 6 localities and the values range from 172° to 221°, and at sector level is 194°. At sector-C, the vector mean was calculated for 2 localities. At locality level the values are 134° and 170° and 151° at the sector level. At sector-D, the vector mean calculated for 3 localities ranges from 159° to 198° at locality level and 182° at sector level. For sector-E, the vector mean was calculated for 4 localities and the values range from 158° to 171° at locality level and at sector level it is 159°. At sector-F the vector mean values calculated for 2 localities are 108° and 117° at locality level and at sector level it is 114°.

Vector strength:

This parameter is necessary to determine the magnitude of the resultant of cos and sin components. Curry (1956) and many others, also indicate that L, the vector strength or consistancy ratio, provides some indication of dispersion.

Vector strength (L%) or consistancy ratio was also calculated at locality level and at sector level. At sector-A, the vector strength ranges from 61 to 92 percent at locality level and is 76 percent at sector level. At sector-B, the vector strength values range from 76 to 97 percent at locality level and 78 percent at sector level. At sector-C, the vector strength calculated for 2 localities ranges from 87 to 96 percent at locality level and 87 percent at sector level. In the case of sector D, the vector strength ranges from 18 to 94 percent at locality level and is 83 percent at sector level. Whereas at sector E, the values range from 67 to 90 percent at locality level and is 88 percent at sector level. At sector F, the values are 82 and 85 percent at locality level and 79 percent at the sector level.

Variance:

The degree of scattering around the mean is measured quantitatively in order to define the population of vector azimuth precisely i.e. we would like to know how much is scattered in terms of frequency rather than saying in a qualitative or descriptive language. The degree of scattering can be measured by calculating variance and standard deviation. If greater the variance - greater will be the scattering, if smaller the variance - less will be dispersion.

The variance (S^2) of foreset dip azimuths at the sector level varies from 376 to 2076 in the area under investigation. These values are the indication of the scattering of dip azimuth about the mean and are numerically equal to the square of standard deviation. The variance significantly shows small variation in the current direction suggesting that the lateral shift is not very prominent.

Interpretation:

Synthesis of the data reveals that the cross-stratification measurements of braided river agree closely with the present current flow patterns. But this is not true for all over the area under investigation. The orientation data showing variation in flow is due to the nature of the river prevailing at the time of deposition of that particular cross-stratified unit. Due to the braided nature the bars restrict the flow to be constant in the same direction for a long distance.

From the flow pattern data it is inferred that the given cross-stratified units deposited by a system of water currents at Hardwar dominantly show the SW flow direction and down stream of Hardwar the flow was in SW and SE direction. At Bijnor the direction of flow dominantly remained in SW, with a minor shift in SE direction. At Sherpur the water currents were flowing in SW and SE direction. Coming down stream at Rajghat, the current direction dominantly remained in SE direction. However, at Kachhla the current flow was in NE and SE direction.

The river shows minor lateral shifting. Further, during the flood, water began to flow over the bank in the form of small channels. The direction of this over flow was not always parallel to the main flow. The sediments deposited on the banks during the flow show large variation in the current direction from the main flow.

FLUVIAL MODEL

The study of geomorphic features, bed forms and lithology provides an opportunity to develop a sedimentation model for the river Ganga. Two separate models have been developed, one for alluvial fan and the other for braided river deposits.

Alluvial Fan Model:

As the deposition is seasonally controlled, so that at the time of high discharge, the river transports more gravels and boulders than sand. The coarse clasts at the base represent deposition by lateral accretion. On the other hand fine sediments represent vertical accretion on top of channel bars (Smith, 1974; Cant, 1978) during periods of minimal discharge. Smaller thickness of fine clasts suggest minimal preservation due to rapid shifting of channel bars Figure 3 shows block diagram of alluvial fan and figure 31 shows generalised sequence of fan deposits.

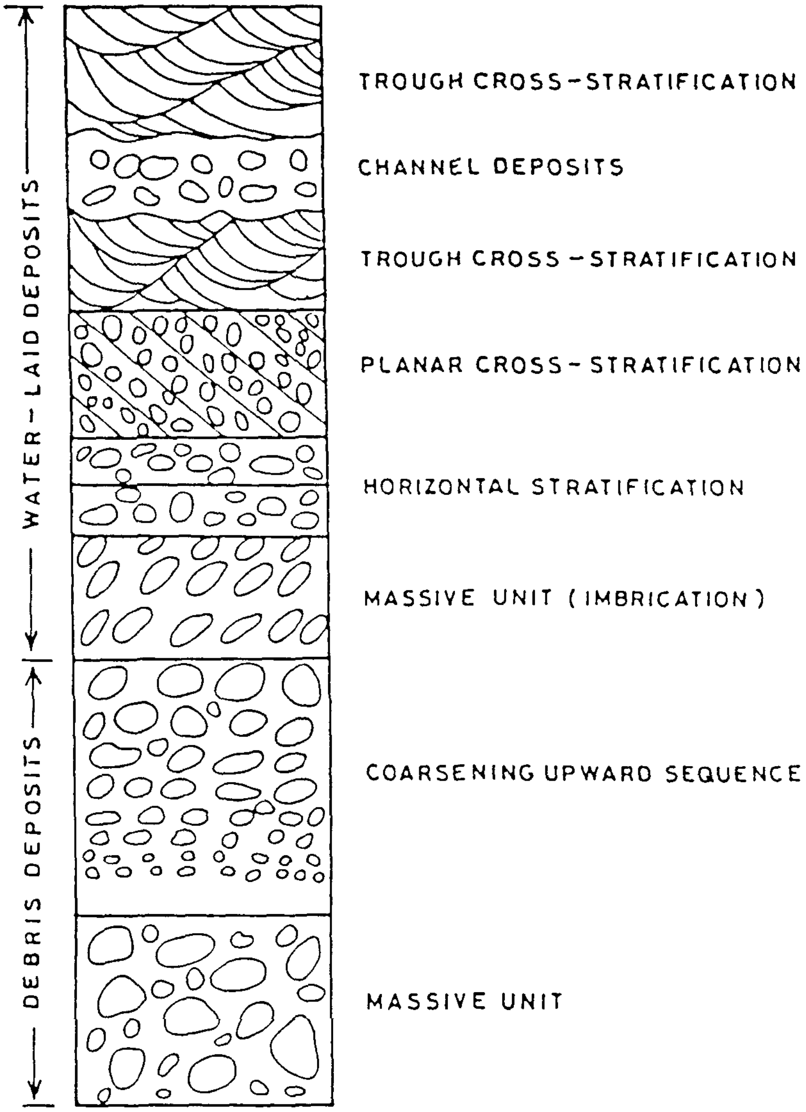


FIG. 31 GENERALISED SEQUENCE OF ALLUVIAL FAN DEPOSITS

The basal part of the fan sequence is represented by massive unit (Fig. 31) which consists sand supported gravels and boulders deposited due to sediment gravity flows. Such gravity flows are interpreted as debris flows initiated by high seasonal flood on unstable, weathered slopes (Morison and Hein, 1987, p. 208). The massive unit is followed by coarsening upward sequence. The lower part of the coarsening upward sequence is marked with sand and upper part with gravels and boulders. This coarsening upward sequence representing debris deposits is the result of progradation of fan (Rust and Koster, 1984; Watts, 1988; Datta, 1988). The proximal coarse clastic debris deposits are overlain by medial and distal fine clasts of water-laid deposits. Heward (1978) described the coarse grained proximal fan deposits overlain by fine grained distal fan deposits. The coarsening upward sequence is overlain by the unit of imbricated clasts of medial facies. The imbrication is developed when the individual clasts were reworked and moved freely with respect to each other. It is interpreted, as the size of imbricated clasts is quite large which implies that the current velocities would have to be very high to develop such a fabric (Morisor and Hein, 1987, p. 210). The imbrication unit is followed by horizontal stratification. The horizontal stratification was developed due to the sedimentation on the surface of the bar under high current velocities. The horizontal stratification is followed by planar cross-stratification. During the development of planar cross-stratification, the sediments were migrated on the bar surface and slip on the avalanche face resulting planar cross-stratification. Morison and Hein (1987, p. 211) interpreted planar cross-stratification as being deposited by down stream progradation of high relief barforms. The planar cross-stratification of medial fan facies is overlain by trough cross-stratification of distal fan facies. Gravelly sand trough cross-stratification is interpreted as the deposits of large scale three dimensional ripples or dunes (Morison and Hein, 1987, p. 211). The trough cross-stratification is overlain by channel deposits which consists boulders and gravels. Due to the erosional nature of bounding surfaces, these deposits are interpreted as channel lag deposits. The channel deposits are overlain by trough cross-stratification.

Braided River Model:

The braided river deposits are comprised of fine clasts in comparison to alluvial fan deposits. Figures 32, 33, 34, 35, 36 & 37 show distribution of sedimentary structures and lithology at Hardwar, Sherpur, Garhmukteshar, Rajghat and Kachhla respectively. The separate generalised sequences (Fig. 38) have been developed for the above mentioned areas.

INDEX TO THE FIGURES

FOR SEDIMENTARY STRUCTURES

A. Large scale planar cross-stratification.

B. Large scale trough cross-stratification.

C. Small scale planar cross-stratification.

D. Small scale trough cross-stratification.

E. Horizontal stratifications.

F. Large scale ripple drift cross laminations.

G. Small scale ripple drift cross laminations.

H. Parallel laminations.

I. Convolute laminations.

J. Leuticular bedding.

K. Massive unit.

L. Channel deposits.

FOR LITHOLOGY

g. Gravel

gs. Gravel and sand.

s. Sand

sc. Silt and Clay

scs. Sand, silt and clay

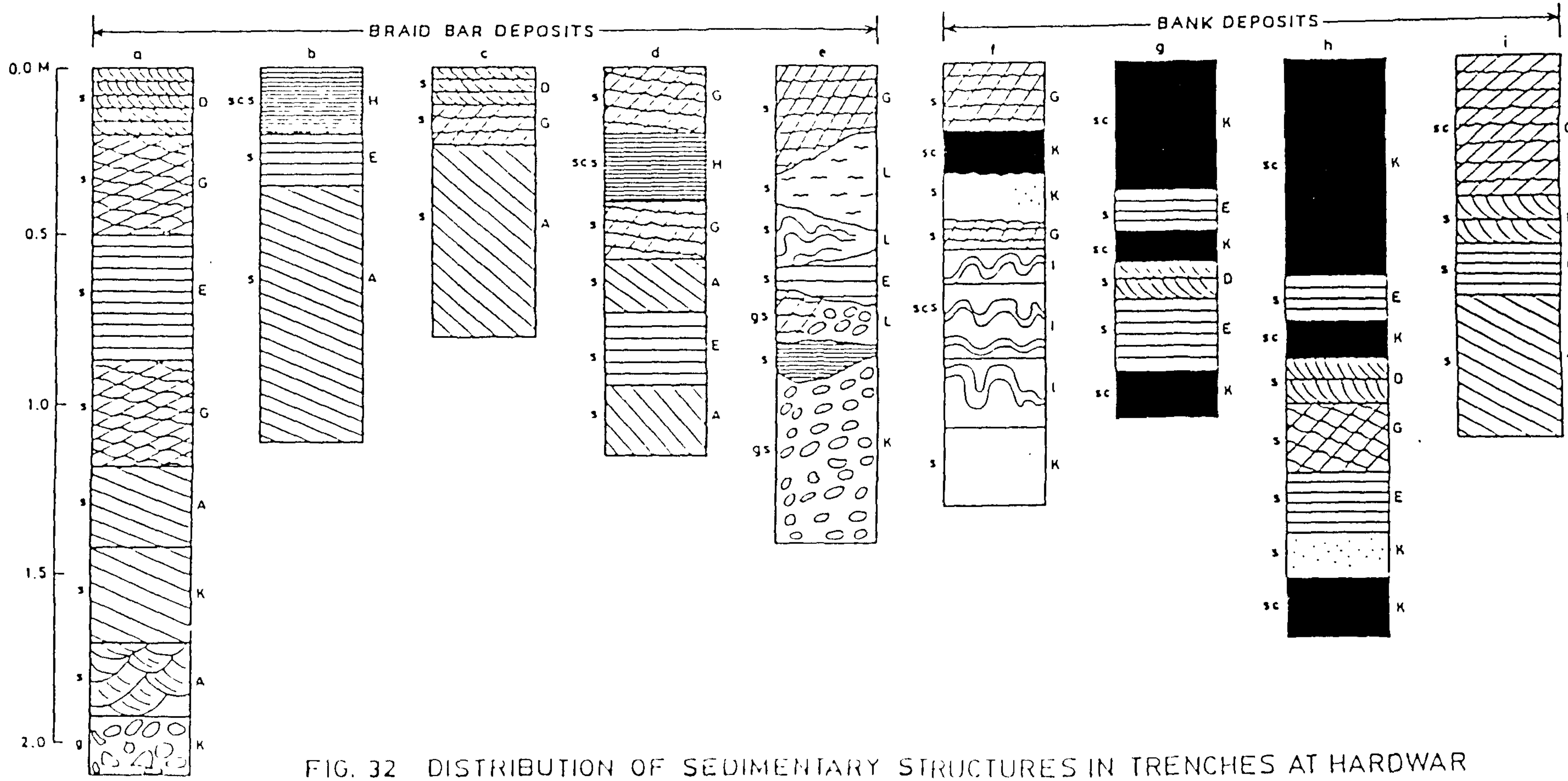


FIG. 32 DISTRIBUTION OF SEDIMENTARY STRUCTURES IN TRENCHES AT HARDWAR

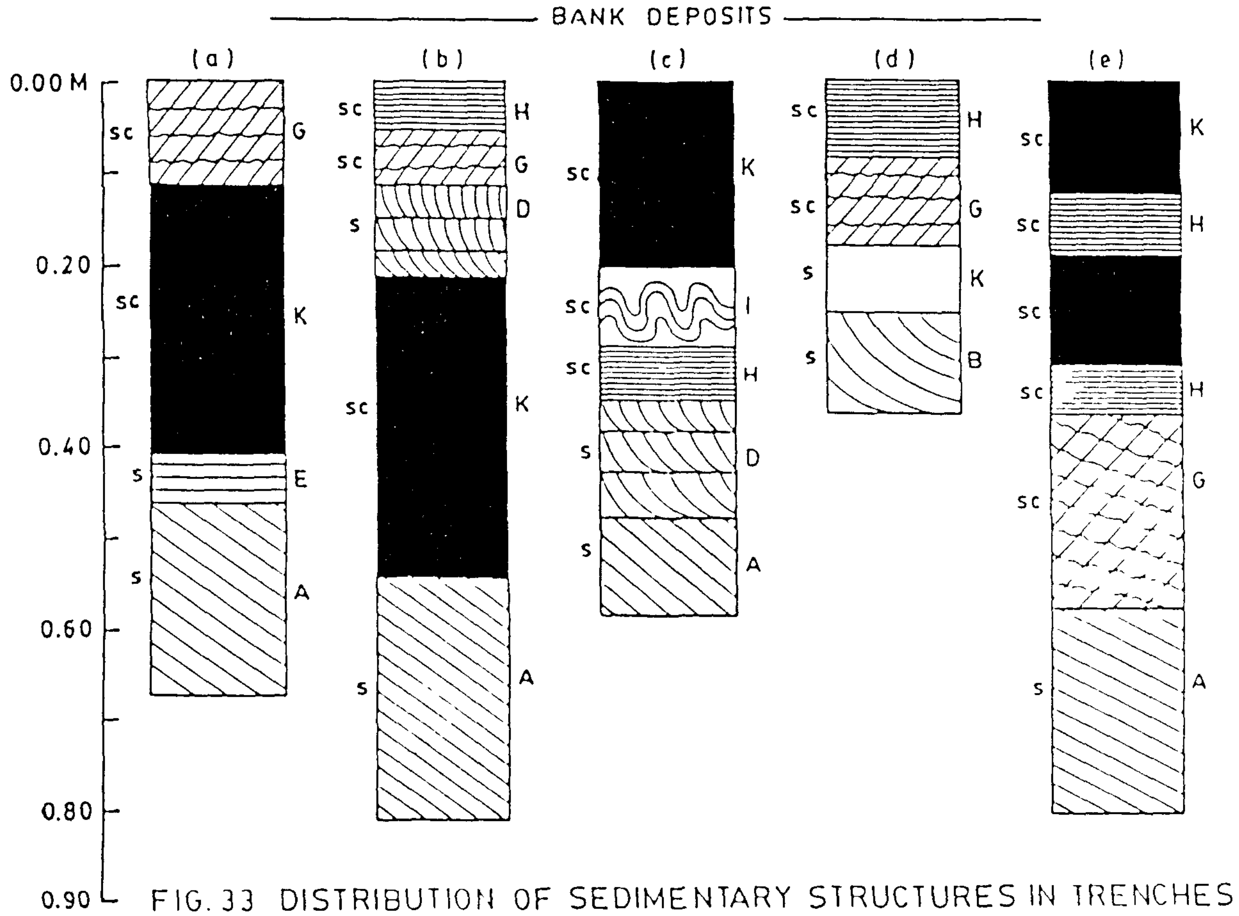


FIG. 33 DISTRIBUTION OF SEDIMENTARY STRUCTURES IN TRENCHES AT SHERPUR

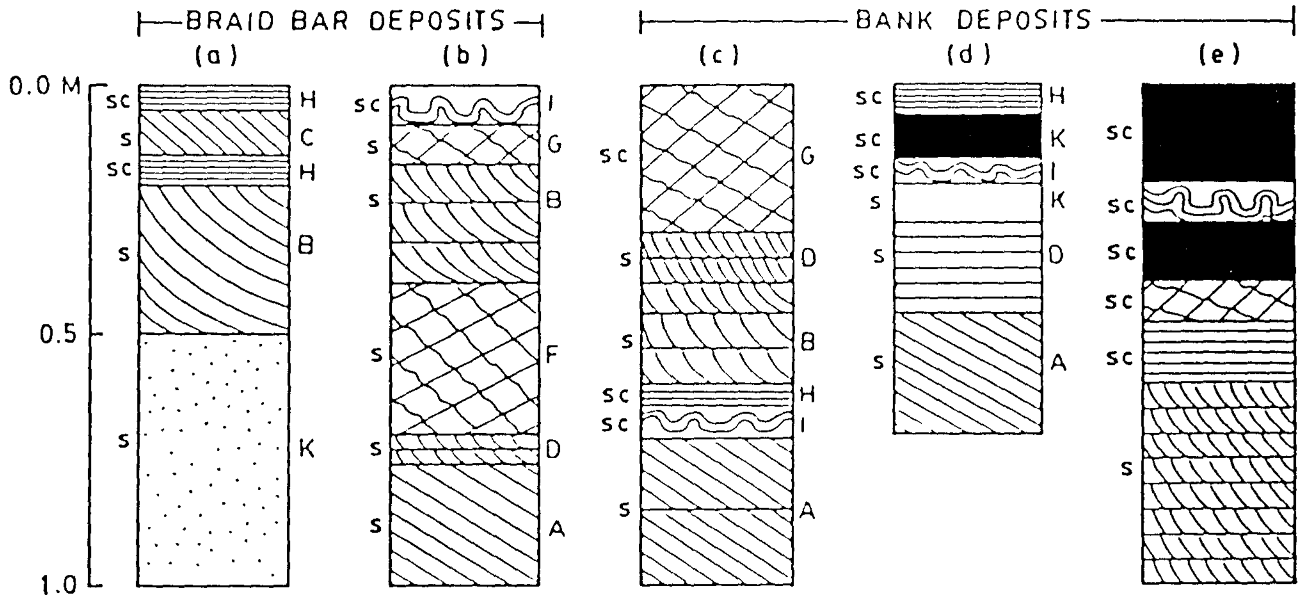


FIG 34 DISTRIBUTION OF SEDIMENTARY SRUCTURES IN TRENCHES AT GARHMUKTESHAR

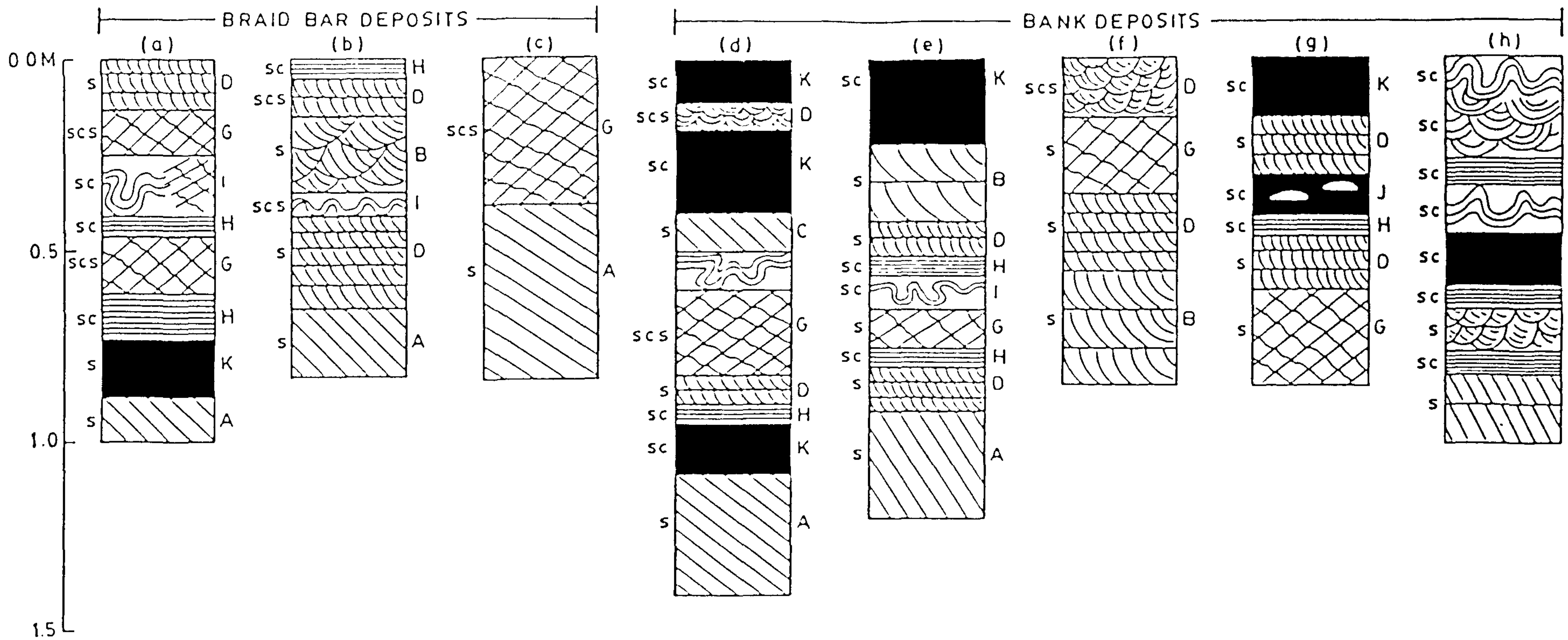


FIG. 35 DISTRIBUTION OF SEDIMENTARY STRUCTURES IN TRENCHES AT RAJGHAT

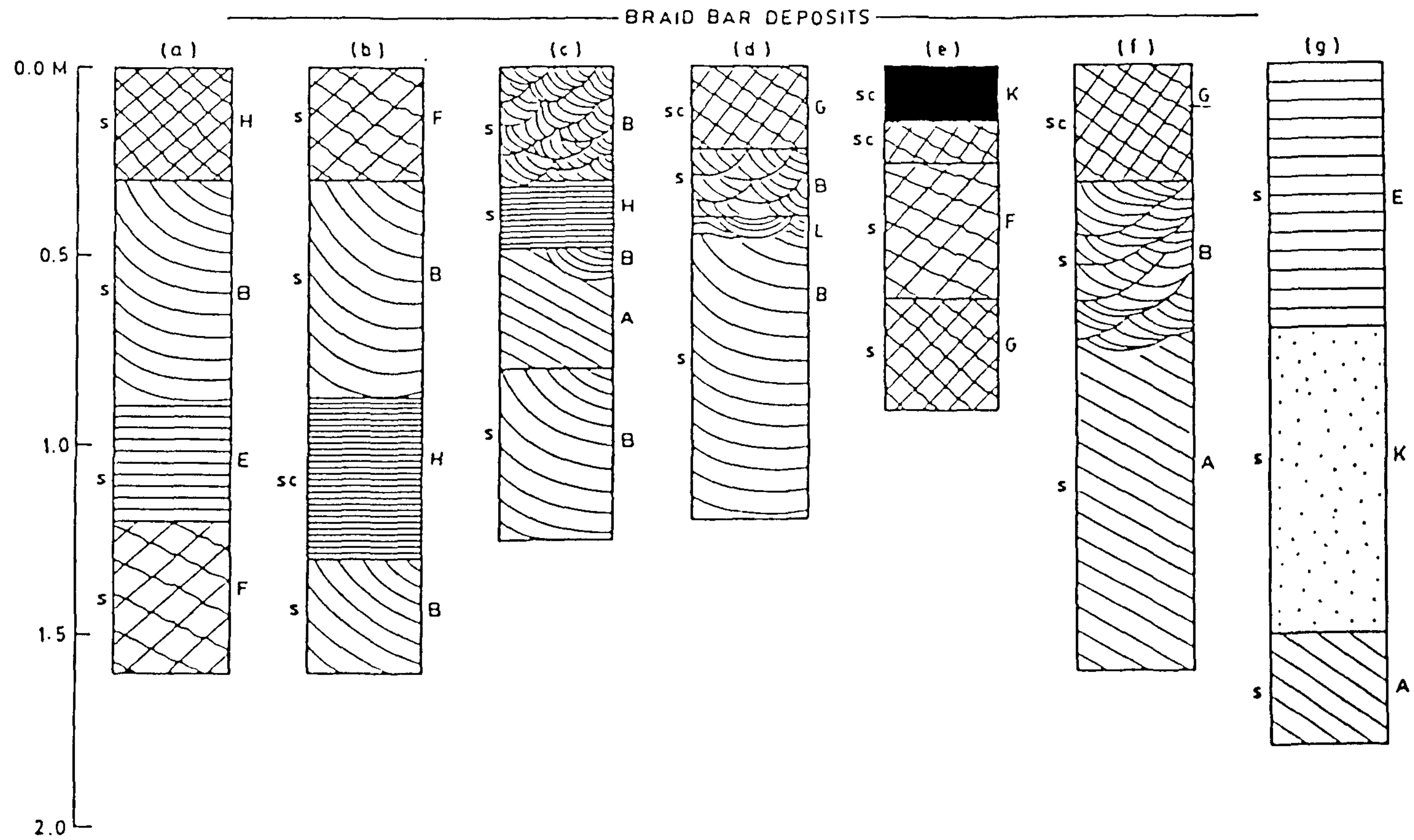


FIG 36 DISTRIBUTION OF SEDIMENTARY STRUCTURES IN TRENCHES AT KACHHLA

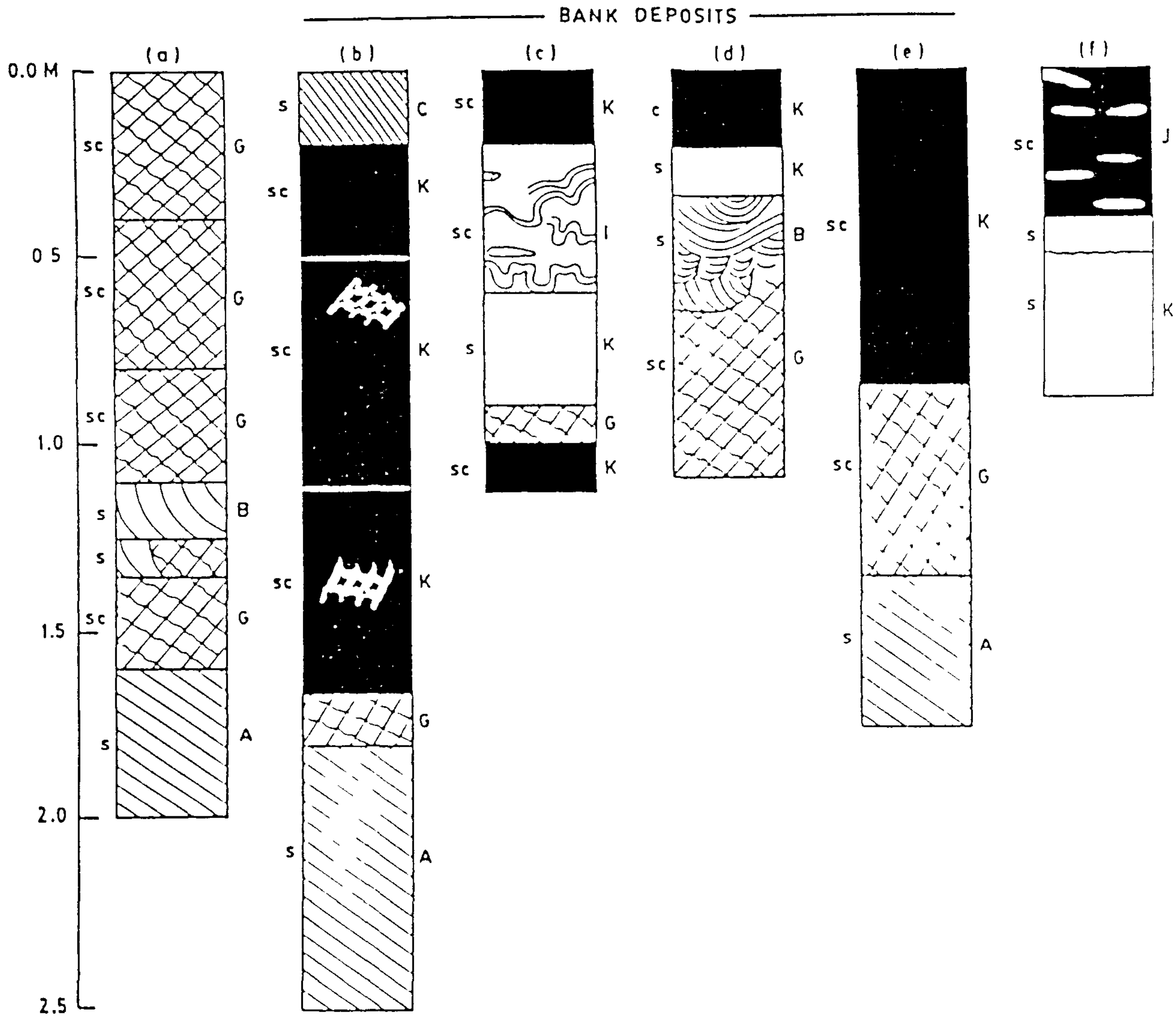


FIG. 37 DISTRIBUTION OF SEDIMENTARY STRUCTURES IN TRENCHES AT KACHHLA

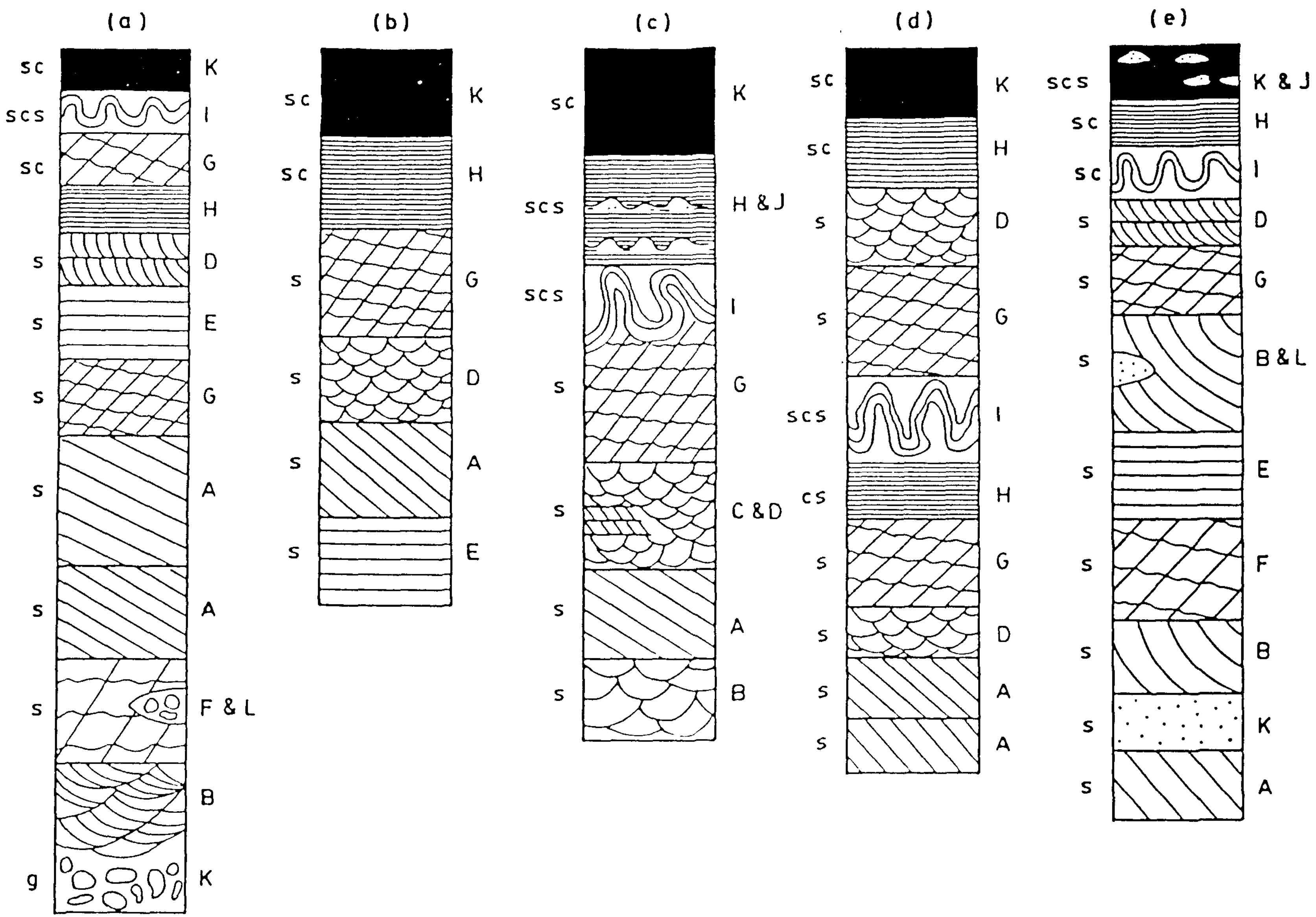


FIG. 38 GENERALISED SEQUENCES AT (a) HARDWAR, (b) SHERPUR, (c) GARHMUKTESHAR, (d) RAJGHAT AND (e) KACHHLA

The generalised sequence (Fig. 38a) at Hardwar shows gravelly channel deposits at the base which is overlain by large scale sandy trough cross-stratification and large scale ripple drift cross laminations. Large scale ripple drift cross laminations are interrupted by gravelly channel deposits and is overlain by large scale planar cross-stratification. Large scale planar cross-stratifications are followed by small scale ripple drift cross laminations and horizontal stratification. The upper part consisting fine sediments is represented by small scale trough cross-stratification, parallel laminations, small scale ripple drift cross laminations, convolute laminations and muddy massive unit in ascending order. The upper part is marked with grass roots.

Figure 38b is the generalised sequence at Sherpur. The basal part shows horizontal stratification followed by large scale planar cross-stratification, small scale trough cross-stratification, small scale ripple drift cross laminations, parallel laminations and massive muddy unit at the top.

Figure 38c show generalised sequence at Garhmukteshar. Large scale trough and planar cross-stratifications occur in the lower part and are overlain by small scale trough and planar cross-stratifications (Fig. 38c). Small scale trough cross-stratification interrupted by small scale planar cross-stratification is overlain by small scale ripple drift cross laminations followed by convolute laminations, parallel laminations and lenticular bedding. The top of the sequence is marked by the presence of muddy massive unit.

At Rajghat the river shows frequent shifting in the channel course. Figure 38d is the generalised sequence at Rajghat. Lower part of this sequence is represented by large scale planar cross-stratification and is overlain by small scale trough cross-stratification. Small scale trough cross-stratification is overlain by small scale ripple drift cross laminations which are followed by parallel laminations and convolute laminations. Convolute laminations are followed by small scale ripple drift cross laminations, small trough cross-stratification, and parallel laminations. Top of the sequence is marked by presence of muddy massive unit.

Further coming down at Kachhla, the river shows well preserved braid bars and bank deposits. The generalised sequence (Fig.38 e) showing large scale planar cross-stratification in the lower part is followed by sandy massive unit, large scale trough cross-stratification, large scale ripple drift cross laminations and horizontal stratification. Horizontal stratification is overlain by large scale trough cross-stratification, interrupted by channel deposits. Large scale trough cross-stratification is followed by small scale ripple drift cross laminations, small scale trough cross-stratification, convolute laminations and parallel laminations. Top of the sequence is marked by the muddy massive unit and lenticular bedding.

On the basis of observations made from the trenches and generalised sequences developed for each area, the two sets summarising the complete sequence for braid bars (Fig.39) and bank deposits (Fig. 40) have been developed. Further summarising various bedforms and stratifications have been shown in a block diagram (Fig. 41).

Braid bar sequence: The basal part of braid bar sequence is marked with gravel deposits (Fig. 39). The gravels were transported under high current velocities and deposited as channel lag deposits. The gravelly channel deposits are followed by large scale trough cross-stratification and correspond the deposition by sand dunes, sand waves, and transverse and linguoid bars in shallow water (Collinson, 1970; Smith, 1972; Miall, 1977). The large scale trough cross-stratification is overlain by large scale ripple drift cross-laminations interrupted by gravelly channel deposits. The gravelly channel deposits surrounded by fine sediments indicates sudden increase in current velocity due to which channel was eroded and subsequently filled in response to fall in current velocity. The large scale ripple drift cross laminations represent

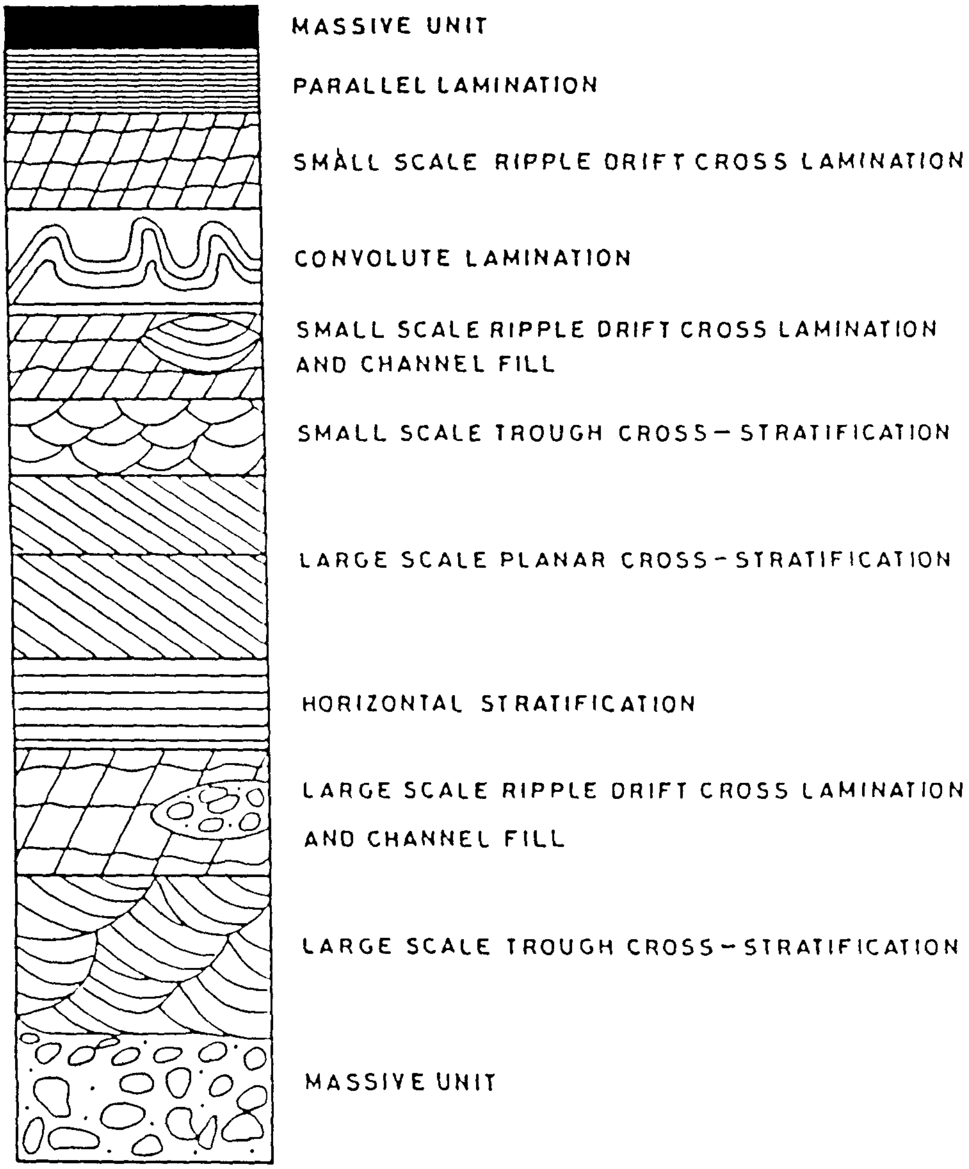


FIG. 39 GENERALISED SEQUENCE OF BRAID BAR DEPOSITS

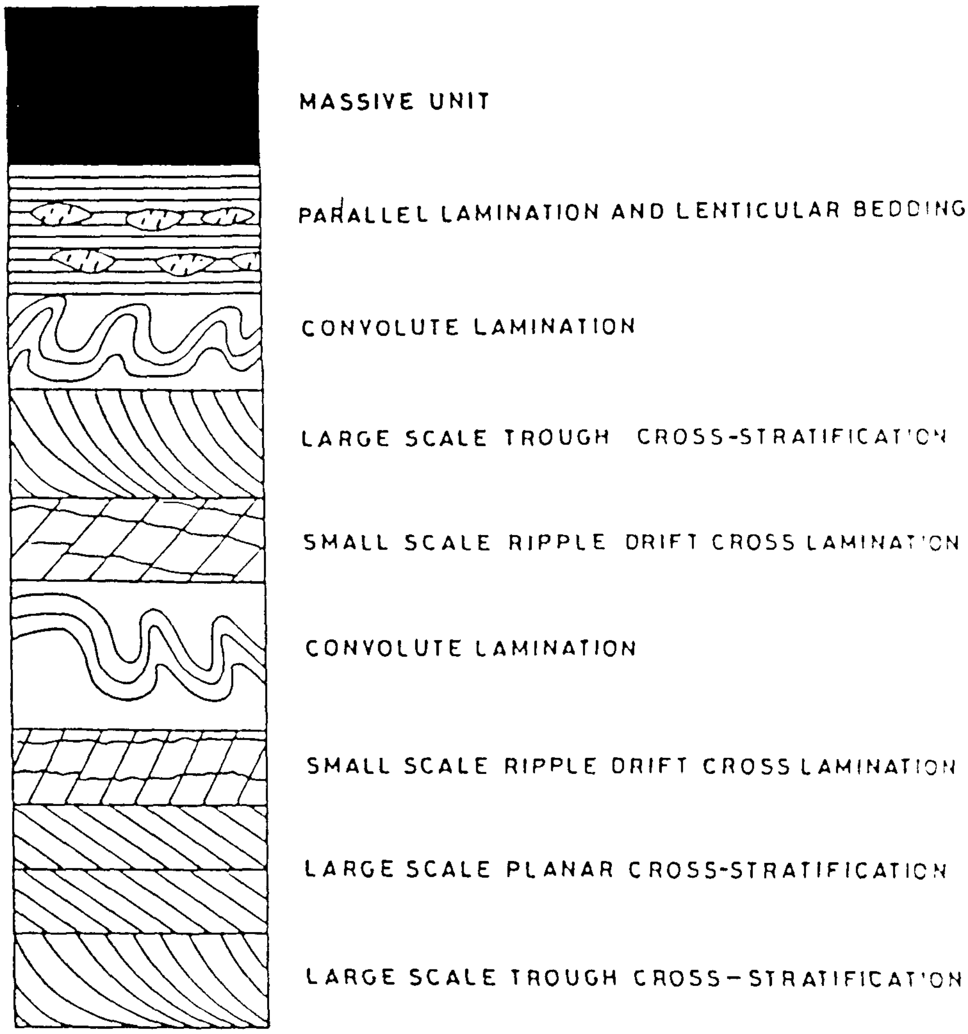


FIG. 40 GENERALISED SEQUENCE OF BANK DEPOSITS

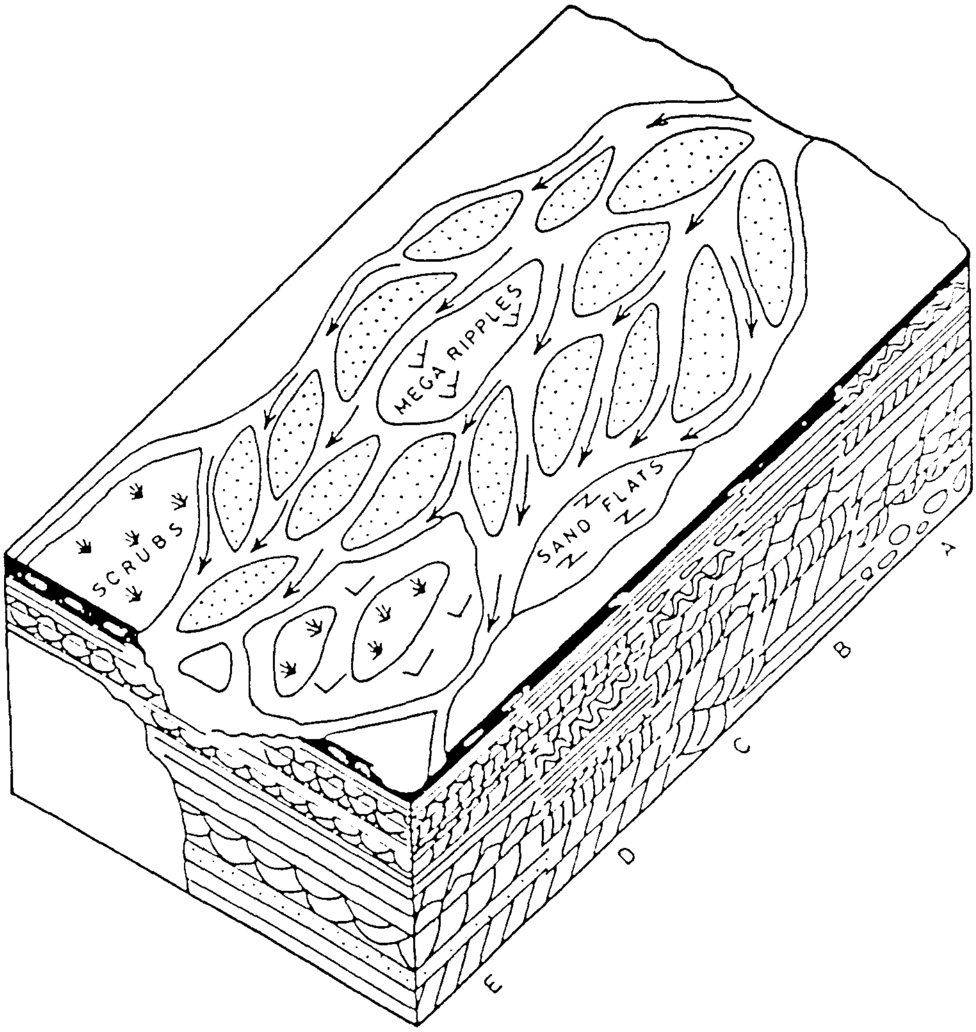


FIG. 41 BLOCK DIAGRAM SHOWING BEDFORMS AND STRATIFICATION OF THE BRAIDED RIVER GANGA. A-LOCATES STRATIFICATION SEQUENCE AT HARDWAR, B- AT SHERPUR C-AT GARHMUKTESHAR, D-AT RAJGHAT AND E-AT KACHHLA

supply of coarse sand in large amount and simultaneous upward growth of ripples. The ripple drift cross laminations were followed by horizontal stratifications which were developed under upper flow regime conditions. Horizontal stratification is overlain by large scale planar cross-stratification suggesting the migration of sediments on the bar surface and deposited on the avalanche face. The overlying small scale trough cross-stratification was developed under lower flow regime conditions. The small scale trough cross-stratification is over lain by small scale ripple drift cross laminations which is interrupted by channel fills. The sediments filled in channels are conformable with the shape of the channel suggesting the deposition under suspension conditions. After deposition of ripple drift cross laminations there was further fall in current velocity depositing silt and clay in which convolute laminations were developed. Field relations suggest that the convolute laminations were developed at the later stage of deposition when the sediments were in the conditions of quick sand. Convolute laminations are overlain by small scale ripple drift cross laminations suggesting a slight increase in velocity than the underlain silt and clay. Ripple drift cross laminations are followed by parallel laminations. The parallel laminations consisting sand were developed under upper flow regime conditions when the river was in flood. The top of the sequence is marked with muddy massive unit. This unit was deposited during waning flood. The whole sequence represents the different cycles of sedimentation.

Bank sequence: The basal part of the bank sequence begins with large scale trough and planar cross-stratifications indicating high phase of lower flow regime under which large ripples migrated resulting planar and trough cross-stratifications (Fig. 40). The planar cross-stratification is overlain by small scale ripple drift cross laminations. This indicates the abundance of sediments being deposited from suspension (Mckee, 1966). This is followed by the deposition of silt and clay suggesting further decrease in velocity. The silt and clay is marked with the development of convolute laminations indicating no current significance and may be post depositional feature. The convolute laminations are overlain by ripple drift cross laminations suggesting slight increase in velocity and, in turn, is overlain by large scale trough cross-stratification which indicates further increase in current velocity. After the deposition of large scale trough cross-stratification the velocity again decreased under which silt and clay was deposited which is marked with convolute laminations. The convolute laminations are overlain by parallel laminations interrupted by lenticular bedding. The development of parallel laminations was under suspension conditions. The presence of lenticular bedding consisting sand is the indication of fluctuating conditions during the development of parallel laminations. The top of the sequence is marked with muddy massive unit which indicates the extremely slow moving conditions of water.

The whole sequence represents the different cycles of deposition indicating fluctuating conditions of deposition. Each cycle starts with coarse sediments and ends with fine sediments.

The proposed models developed provide a systematic development of processes and products for Ganga River sediments in the area under study. The alluvial fan model shows both coarsening and fining upward sequences. The gradual upward increase in clast size in the lower part of alluvial fan sequence (Fig. 31) represents progradation and gradual upward decrease in clast size is an indicative of fan recession (Heward, 1978; Kingsley, 1987 p. 368).

The braided river model represents fining upward sequence. The fining upward sequence represents the gradual upward decrease in current flow strength during deposition (Morison and Hein, 1987, p. 212). Vertical deposition during wanzing discharge produces upward fining (Smith, 1974). Such fining upward sequence formed by diminishing flow is characteristic in bars produced during a single discharge cycle.

CHAPTER VI

SUMMARY AND CONCLUSION

The river Ganga rises in the Garhwal Himalaya (30° 35'N, 79° 7'E). The source of Ganga is the ice cave of Gaumukh at the snout of the Gangotri glacier, about 4100 meters above sea level. The river Ganga is one of the largest rivers in India, draining as much as 861,404 square km. within the country. The Ganga basin covers more than a quarter (26.2 percent) of the Indian geographical area. The river has large surface water and ground water source with an annual flow of 468.7 billion (thousand million) cubic meters (25.2 percent of Indian total water resource). The discharge of the river is seasonally controlled. The river maintains low discharge in winter season and the discharge increases in the late spring. In rainy season discharge reaches its peak in the month of July and August and decreases in October and November. The course of the river and sedimentation pattern is controlled by the E-W running weak zones. The thickness of alluvium is 500-1000m near foot hills and decreasing sothwards, where it may be tens of meters thick .

The study was carried out from Rishikesh in the north of western Uttar Pradesh through Hardwar, Bijnor, Sherpur, Garhmukteshar, Rajghat to Kachhla. The study includes processes and products, sedimentary facies, textural attributes, mineral composition, flow pattern and models of alluvial fan around Rishikesh and braided river deposits from Hardwar to Kachhla.

The main conclusions of this **study** are summarised here as under:

1. The alluvial fan deposits are developed around Rishikesh. Present day active alluvial fans make only 20-30 km. wide belt. The deposits include gravels, boulders, sandy gravels and sand. On the basis of the nature of deposits, orientation of clasts, stratification, lithology and gradation in sediment size, the alluvial fan deposits have been divided in three facies, namely proximal, medial and distal fan facies.

The proximal facies includes gravels and boulders with small amount of sand matrix. The gravels and boulders are oriented randomly and have no stratification. The deposits of proximal facies are described as debris deposits. Debris deposits include massive unit (Gms) and coarsening upward sequence (Gms). Massive unit (Gms) is poorly sorted, sand matrix supported (about 10-15% sand matrix). The gravels and boulders are randomly oriented, deposited due to gravity flows in the proximal part. Coarsening upward sequence (Gms) represents progradation of fan. It is a local phenomena. All these features reflect that the proximal facies is developed on higher gradient.

The medial and distal facies are marked with well developed stratification. There is gradation in the size of gravels and boulders as compared to proximal facies. The sand content increases in these facies. These stratified gravelly and sandy deposits have been described as water-laid deposits. The horizontal stratification (Gh), planar cross-stratification (Gp) and imbricated (Gm) deposits have been described as sheet flood deposits. Those deposits which are in the form of lobes consisting gravels and sand have been described as sieve deposits. Sheet flood and sieve deposits are developed in the medial facies. The horizontal stratification consisting gravels with sandy matrix indicates that gravels and sand both were deposited simultaneously. The planar cross-stratification (Gp) indicates the migration of gravels with sand on the bar surface and deposited on the slip face. This reflects the bar growth. Sieve deposits indicate perculation of water due to which the gravels and sand were deposited in the form of lobes.

The trough cross-stratification (St) and channel deposits developed in the distal facies have been described as stream channel deposits. Trough cross-stratification (St) indicates low velocity conditions developed due to migration of dunes with sinous crest line. The channel deposits (Gs) indicates erosion of channel due to high velocity currents. As the velocity decreases the gravels with sand were deposited. These deposits are described as channel lag deposits.

Distinctive lithofacies, lithofacies assemblage, geometry, loss of radiating sediment dispersal pattern, gradation in the size of sediments separate the alluvial fan deposits from the braided river deposits. The alluvial fan deposits gradually merges in the braided river deposits.

2. The braided river facies from Hardwar to Kachhla include Gravelly channel facies (Gs), sandy channel facies (Ss), trough cross-stratified sandy facies (St), planar cross-stratified sandy facies (Sp), ripple drift cross laminated sandy facies (Sr), convolute laminated fine sand, silt and clay facies (Fc), parallel laminated fine sand, silt and clay facies (Fl), massive sandy (Sm) and massive silt and clay facies (Fm) and lenticular sandy facies (Sl).

Gravelly channel facies (Gs) consisting gravels embedded into medium to fine sand indicates channel lag deposits. The sandy channel facies (Ss) comprising coarse to fine sand represents submerged and fluctuating conditions. Sediments conforming the shape of the channel indicates submerged condition. However, the channel consisting horizontal and planar cross-stratification indicate fluctuating conditions. The trough cross-stratified sandy facies consisting coarse to medium sand show scouring and filling due to migration of small and large scale sinuous crested ripples. The planar cross-stratified sandy facies (Sp) represents migration of straight crested ripples and sand sheets deposited on avalanche face. Ripple drift cross laminated sandy facies (Sr) comprising of sand and small amount of silt indicates high rate of sedimentation under low velocity conditions when there was continuous supply of sediments. Convolute laminated facies (Fc) consisting fine sand, silt and clay is the result of lique-faction or unequal loading. Parallel laminated facies (Fl) developed in fine sand is the result of upper flow regime, while those developed in silt and clay are the result of lower flow regime conditions. Massive (Sm) facies developed in channel bars comprising of medium to coarse sand is the result of rapid sedimentation under high energy conditions, while massive (Fm) facies developed in bank deposits comprising silt and clay indicates its development due to heavily laden water currents during waning flood stage. Horizontal stratified sandy facies (Sh) consisting coarse to fine sand represents both high velocity and low velocity currents. Lenticular sandy facies (Sl) represents fluctuating conditions.

3. The grain size analysis was carried out to study the vertical and down stream variation in size of sediments with particular facies. The large scale trough and planar cross-stratification, ripple drift cross laminations developed in the lower part of the channel sequence consist very coarse to coarse sand with small amount of medium sand. The upper part of the channel sequence contain fine sand with small amount of silt and clay. The size of the sand decreases vertically with the change in facies. The bank deposits contain fine sand, silt and clay in which small scale ripple drift cross laminations, parallel laminations, convolute laminations and massive mud facies have been developed. The vertical and down stream decrese in the grain size is observed from Hardwar to Kachhla. At Hardwar the sand is very coarse to fine sand and mean size varies from 1.4 Φ to 3.3 Φ. At Sherpur the sand is coarse to very fine and mean size varies from 2.0 Φ to 3.16 Φ. Garhmukteshar sediments consist coarse to very fine sand with mean size varying from 2.0 to 3.8 Φ. At Rajghat the sand is coarse to very fine grained with mean size varying from 2.0 to 4.0 Φ. At Kachhla the sand is coarse to very fine grained with mean size varying from

2.1 to 3.71 ϕ. The amount of coarse sand decreases in down stream direction. However, the amount of fine sand increases vertically and in down stream direction.

The grain size analysis reveals that the sediments were transported by three processes namely traction, saltation and suspension. The proportion of traction population is small and sporadic in nature implying variation in the intensity of depositing currents. The poor and fair sorting of traction population again suggests varying current velocity and turbulance during deposition. Saltation process is the dominating process due to which bulk of the sediment load was deposited. Good to excellent sorting of the saltation population reveals reworking of sediments. The suspension population is highly variable. Higher percentage of this population indicates rapid sedimentation under last phase of deposition.

It is concluded that the saltation population reveals reworking of sediments, slow rate of sedimentation and stable bed layer of saltating grains. This process was most effective during the deposition of all the three types of populations. However, traction and suspension populations were more effective in type II grain size distribution.

The sample analysed for roundness indicates increase in roundness with distance of transport. At Hardwar the mean roundness varies from 0.249 to 0.364, at Sherpur the mean roundness varies from 0.345 to 0.411. Coming down at Garhmukteshar, the mean roundness varies from 0.338 to 0.421 and at Rajghat, it varies from 0.370 to 0.402. The mean roundness at Kachhla varies from 0.345 to 0.375 . The coarser sand grains are more rounded than finer sand grains. The coarser grains got rounded as they collided each other with greater impact during transportation along the surface. The harder grains like tourmaline which are well rounded are the recycled grains.

The sphericity values of gravel clasts range from 0.3 to 0.9. The sphericity values at Rishikesh range from 0.4 to 0.8. Covering about 12 km. distance in down stream the sphericity values at SaptRishi are 0.3 to 0.9. Further coming about 7 km. in down stream the sphericity values at Hardwar are 0.4 to 0.9. Most of the gravel clasts have moderate sphericity. Hard and compact clasts have high sphericity which increases with decrease in size and increase in the distance of transport. The sphericity of weaker clasts is lower and decreases with the increase in the distance of transport.

4. A large number of minerals are present in the Ganga sand. Light minerals examined from Ganga sand are quartz, orthoclase, and plagioclase, Rock fragments of quartzite, schist and phyllite are present. Among the heavy minerals various species are tourmaline, garnet, zircon, opaques, titanite, spinel, muscovite, sillimanite, chlorite, hornblende, kyanite, epidote, staurolite, anatase, hypersthene,

actinolite/tremolite, zoisite, biotite, rutile and apatite.

Heavy mineral species reveals a variety of rock types present in the source area. These heavy mineral species have been derived from mixed assemblages of acid and basic igneous rocks and low to high grade metamorphic rocks. Presence of well rounded tourmaline indicates more than one cylce of transport revealing its derivation from sedimentary source. The presence of tourmaline, garnet and zircon indicates the higher energy of depositing agent. The grains are distributed in varying proportions. The heavy species examined from Hardwar are thick and bigger in size. However, the heavy species examined from Rajghat and Kachhla are thin and smaller in size. With the transport the grains are abraded and reduced in size due to which sedimentary characters are clearly visible.

5. The flow pattern of the river Ganga agrees with the present flow pattern though some exceptions are there. At Hardwar the flow is in SW direction and down stream of Hardwar it remains in SW and SE direction. At Bijnor flow dominantly remained in SW showing minor shift in SE direction. Further, comming down stream flow is in SW and SE direction while at Rajghat it is in SE direction. At Kachhla the flow of river is in NE and SE direction.

6. The poximal facies of the alluvial fan model represents debris deposits. The basal part of the proximal facies is marked with massive unit (Gms) consisting gravels and

boulders with sand matrix. It is followed by next unit indicating coarsening upward sequence. The size of clasts of this coarsening upward sequence increases vertically from coarse sand to gravels and boulders. This coarsening upward sequence may develop due to progradation of proximal facies for short duration. The debris deposits are followed by water-laid deposits of medial and distal facies. The coarsening upward of debris deposits is followed by massive unit of water-laid deposits in which gravels and boulders are imbricated. It is followed by horizontal stratification and planar cross-stratification. These deposits of medial facies are followed by sandy trough cross-stratification and gravelly channel deposits of distal facies. The medial and distal facies of water-laid deposits indicate fining upward sequence. This fining upward sequence indicates recession of fan.

The channel and bank sequence of the braided river model represent fining upward sequence. The basal part of the channel sequence if marked with large scale facies developed in gravels and coarse sand. The upper part shows small scale facies developed in fine sand, silt and clay. In the lower part of channel sequence the gravelly channel, large scale trough and planar cross-stratifications, large scale ripple drift cross laminations, sandy channels have been developed. In the upper part small scale trough and planar cross-stratifications, ripple drift cross-laminations, parallel laminations, convolute laminations, lenticular bedding and massive mud facies have been developed. The most of the sediments in channel have been deposited due to saltation process. The sediments of bank sequence are finer than the channel sequence. The amount of silt and clay is higher in the bank sequence. In the bank seqquence the sediments have been deposited due to suspension. Small scale ripple drift cross laminations, parallel laminations, convolute laminations, lenticular bedding and massive mud facies have been developed. Both channel sequence and bank sequence represent fining upwwar sequence.

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Sedimentological studies of Ganga River sediments between Rishikesh and Kachhla, Uttar Pradesh

ABSTRACT

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ABSTRACT

The Ganga River rises in Garhwal Himalaya (30° 35'N, 79° 7'E) from Gangotri glacier draining as much as 861, 404 square Km. within the country. The river has large surface water and ground water source with an annual flow of 468.7 billion cubic meters (25.2 percent of Indian total water resource. The discharge of the river is seasonally controlled. The study was carried out from Rishikesh in the North of Western Uttar Pradesh through Hardwar, Bijnor, Sherpur, Garhmukteshar, Rajghat to Kachla.

The Ganga River sediments between Rishikesh and kachhla ranging in thickness from more than 1000m to 350m and covering an area of about 350km. in length provide an excellent opportunity to study the fluvial sedimentary facies, textural attributes, mineral composition, flow pattern and depositional model.

The river Ganga emerges on the plain at Rishikesh where alluvial fans have been deposited. However, in down stream from Hardwar to Kachhla the river is marked with the braided river deposits.

The fan deposits have been divided in three facies namely proximal, medial and distal. Proximal facies is marked with debris deposits which shows massive units (Gms) and coarsening upward sequence (Gms). Medial and distal facies are marked with sheet flood deposits, sieve deposits and stream channel deposits. Water-laid deposits show

development of imbrication (Gm), planar cross-stratification (Gp), horizontal stratification (Gh) and the stream channel deposits (Gs).

The braided river deposits from Hardwar to Kachhla show development of various facies. The various facies developed are gravelly channel facies (Gs), sandy channel facies (St), planar cross-stratified sandy facies (Sp), ripple drift cross laminated sandy facies (Sr), convolute laminated fine sand, silt and clay facies (Fc), parallel laminated fine sand, silt and clay facies (Fl), massive sandy (Sm) and massive silt and clay facies (Fm) and lenticular sandy facies (Sl).

The sediments of Ganga River have been deposited by traction, saltation and suspension processes. Bulk of the load is deposited by saltation process. The proportion of traction population is small and sporadic in nature, while suspension population is highly variable. Saltation process was most effective during deposition of all the three types of populations. Roundness and sphericity icncreases in the down stream direction, where as the grain size decreases downwards. A large number of minerals are present in the Ganga sand. Quartz, orthoclase and plagioclase are light minerals. Rock fragments of quartzite, schists, and phyllites are present. The heavy mineral species are tourmaline, garnet, zircon, titanite, spinel, muscovite, sillimanite, chlorite, hornblende, kyanite, epidote, staurolite, anatase, hypersthene, actinotite/tremolite, zoisite, biotite, rutile, apatite and opaques derived from acid and basic igneous rocks and low to high grade metamorphic rocks. Presence of well rounded grains of tourmaline indicates their derivation from sedimentary source.

The dip azimuths of cross-stratified units indicate SW direction of flow at Hardwar and in down stream, it is in SW and SE direction. Further in down strem the flow becomes in SE direction. At Kachhla the river flow is in SE and NE direction.

The basal part of alluvial fan model at Rishikesh indicates debris deposits of proximal facies. The Proximal facies represents coarsening upward sequence. Proximal facies is followed by water-laid deposits of medial and distal facies. Medial and distal facies indicate fining upward sequence. The braided river deposits from Hardwar to Kachhla indicates development of various facies. The sediment size of the facies decreases gradually in the down stream direction. The channel sequence is marked with coarse to medium sand with small amount of silt and clay. However, the bank sequence is marked with fine sand having large amount of silt and clay. The channel and bank sequences represent fining upward sequennce. Both grain size and scale of the facies decrease vertically.